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TOWARD A CLEANER AQUATIC ENVIRONMENT

Kenneth M. Mackenthun

Environmental Protection Agency
Washington, D. C.

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Kenneth M. Mackenthun
Director, Technical Support Staff

ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF AIR AND WATER PROGRAMS

1973

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The scenic grandeur of unspoiled nature.

Foreword

PROTECTION from pollution and quality enhancement of the environmental resources of this Nation are challenges that must be met by our modern society. We have an innate obligation to those who follow in our footsteps to deliver to them a water resource that can meet the use demands of their generation. Positive actions to ensure the attainment of this goal must be accelerated to compensate for continued pressures of population and industrial growths, urbanization, and technological changes.

One key to our success will be the extent to which we, as a society, can define and understand the quality and behavior of the aquatic environment. To correct situations already bad, we must be aware of the alternatives available for correction, and we must be in a position to weigh the potential environmental effects of each alternative before reaching a sound decision for an appropriate course of action. Determination of the quality of the aquatic environment, the effects of pollutants on that quality, and the causes and control of plant and animal nuisances that result in costly problems are critical elements in the scientific efforts needed for decision making. This book is devoted to a definition of those causes and effects and will be a valuable contribution to assist those who are involved in the applied aspects of water pollution control.

Robert W. Fri, Acting Administrator
Environmental Protection Agency

Preface

THIS book was prepared to provoke concern for the control of water pollution and to serve as a guide in the investigation and definition of problems associated with the aquatic environment. It has been written principally for use in the curriculum for the upper grades in high schools and in colleges. Hopefully, in addition, it will be found of value by the aquatic biologists inexperienced in field investigative activities, as well as by sanitary engineers, chemists, attorneys, water pollution control administrators, and others who may have need to broaden their understanding of investigative techniques and water quality and technical problems encountered in such studies.

This book is divided into 21 chapters that address: characteristics of the aquatic environment, insults on the aquatic environment perpetrated by man, controls for such insults, constraints on governmental actions, investigations of aquatic problems, reporting the investigative results, biological nuisances, health-related aquatic problems, keys to common algae and rooted aquatic vegetation, and government abatement and control programs. Investigative techniques are described in detail for the pond, stream, and lake environments, and for special studies. The ability to present a clear, understandable concept of the results of a field investigation by different methods of data display is evaluated. Methods of correcting the causes of slime, plant, and animal nuisances are discussed.

The investigation of water-associated problems always is a fascinating challenge to the initiative and imagination of the investigator. Water and the life within it presents a dynamic panorama of action, interaction, and reaction to forces imposed upon the aquatic environment. The physical constraints of the waterway, as well as the regulating actions of temperature, light, wind, and precipitation impose their effects on the unpolluted aquatic ecosystem. These effects may be accentuated when pollution is introduced as an additional factor of concern. As Henry Baldwin Ward wrote in 1918, "From the tiniest rivulet to the mightest river one may find every possible intermediate stage, and between the swiftest mountain torrent and the most sluggish lowland stream there exists every intermediate gradation." No two waterways will be found to be similar and each supports a population of biota that has adjusted to its particular quality conditions for existence.

The investigator of water quality problems should possess the tenacity and persistence of a detective combined with the thoroughness of an attorney preparing a major case for court. The capabilities of even the experienced investigator frequently are taxed to the limit in resolving some of the puzzling features of the complex reaction and interaction of pollution in a receiving waterway.

Clearness in thought and understandability have been the goals in presenting this book's contents. Reference citations have been kept to a minimum, but a short chapter devoted to helpful references should assist the investigator in obtaining the information necessary for a basic study of the aquatic environment. Many such studies can be completed on a local waterway by the individual researcher or in fulfillment of a class project in high school or college. This book hopefully will serve as a reference guide to aid in the successful completion of such projects. It is with these future professional investigators that this generation entrusts the future solution of aquatic problems.

Kenneth M. Mackenthun
Washington, D. C.
January, 1973

Downstream

Its waters were clear as the finest crystal, some say;
But this was two score and five years ago,
Before we ceased to care where rusty parts, and old tires lay,
That now are our rejected symbols of progress and a nation's alter ego.

What once was clean, now is a mixture of translucent grays,
That slide more than flow as in the past,
And prevent the sun's unique and penetrating rays,
From giving life's gift to those creatures who might have been, alas!

In the river's far upstream reaches, life happily yet competes,
Mayflies, caddisflies and an occasional stonefly each have their day;
Finny friends seek food, spawn, and the cycle repeats
Among aquatic pastures where the damsel- and the dragonfly play.

Downstream, life's harsh realities encounter degradation,
Caused by sewage, inadequately treated, and other waste flows,
Which kill, destroy homes, blanket and result in deprivation
Of life, for all except the most tolerant of pollution's woes.

Abundant sludge, foul smelling, soft, deep and more,
Blankets all but the channel of the swiftly-flowing stream,
Covering the bottom with dull, red, undulating sludgeworms and
  bloodworms galore,
Eliminating the less tolerant and happy-water insect larvae, as well
  as the bream.

With the anticipated coming of pollution control's new dawn,
Downstream and upstream quality will hopefully approach the same;
With all the happy waters, and finny friends with spawn,
Clean and pure; an investigator's report can then cast no blame.

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"The nineteen-seventies
absolutely must be
the years when America
pays its debt to the past
by reclaiming
the purity of its air,
its waters and
our living environment.
It is literally
now or never."

President Richard M. Nixon
January 1, 1970

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1

The Environment

THE LAND, the air, and the water are inseparably bound together and interrelated one with the other to form the environment in which we live. When a portion of the universe is degraded because of pollution, another portion is likewise affected. It is well known that pollution from the lands enters watercourses and results in their degradation. Likewise, certain elements such as nitrogen and phosphorus may occur in the atmosphere because of natural phenomena or because of industrial pollution. These elements may in turn be deposited in the immediate drainage basins or on water bodies, and contribute to the fertilization and subsequent stimulation of organisms undesired by man. It has been shown that the nitrogen present in waste matter from confined cattle feeding areas may escape as ammonia to the air and be reabsorbed by surface waters in concentrations above those considered as threshold for the development of eutrophication. On the other hand, there is a loss of nitrogen to the atmosphere from lakes and other standing waters during the processes that comprise the nitrogen cycle and, similarly, there is loss of nitrogen and other nutrients to the soils of the lake bed.

Aquatic Environments

Aquatic environments are as numerous as the very waters themselves. Rising in snowcapped mountains, small streams collect the snow melt and transport it to the plains. As these streams meander through the countryside, they take from the lands that which is released to them. Small streams soon form larger ones that eventually join to form the great rivers and these in turn terminate in coastal estuaries. Each change in size and shape forms a habitat that becomes a unique microcosm and supports an assemblage of organisms that is adapted to life in that particular environment.

Reservoirs, built by man on rivers, in turn form a particular habitat that is influenced principally by the reservoir's morphometric features. The reservoir in turn may influence the downstream environment because of the depth of the penstock that releases water of lower temperature, or of less dissolved oxygen, or of a different mineral quality, than the waters that receive it.

The landscape is dotted with ponds and with many larger lakes of varying sizes and shapes. There are over 1,586,000 lakes, ponds, and reservoirs in the United States (Anon., 1962). Over 90 percent of these are private farm ponds, primarily encouraged and developed for limited withdrawal uses. The populace lives in contact with fresh surface waters of which 90 percent by area are lakes:

Great Lakes	—	33,878,000 acres
Alaskan Lakes	—	7,363,960 acres
Other U. S. Lakes	—	19,493,000 acres
Total		60,734,960 acres

Organisms that may be found in great numbers in the stream environment are often not adapted to life within the lake or reservoir environments, and visa versa. There are many features that tend to make a particular aquatic environment suitable or unsuitable, completely or to some degree, to a particular organism or group of closely associated organisms.

Lakes

Lakes are temporary water-holding vessels on the landscape. Nearly all are very young on the geological time scale but very old on the human time scale. Lakes will disappear. Natural processes tend to destroy lakes, and man's actions tend to accelerate this destruction. Destruction may result from erosion of the natural dam or sill that controls the lake's minimum level. Erosion contributes materials that settle in quiescent waters to eventually fill the lake basins. Poor land practices can increase erosion; thus the rate of sedimentation is increased.

Terrestrial disposal of waste materials may seriously affect a lake where drainage from dumps transport undesirable nutrient and solid materials to waterways. Dumps containing large quantities of organic garbage contribute especially large quantities of such materials. Manure disposal has become a problem because farmers rely more on synthetic fertilizers and waste the natural, less efficient fertilizers. This water pollution problem is intensified in northern climes where runoff over frozen ground may carry these nutrient-rich organic materials to lake or stream. Large cattle feed lots are frequently located directly on a stream bank to ensure water supplies for livestock, but this inappropriate practice greatly increases the contaminants entering the water.

Common practice in many areas is to use a lake as a community dump. Frequently this is justified as a land fill by the local populace to create valuable industrial or residential sites. Besides the addition of nutrients to the water, the lake volume is reduced and less water is left for other purposes.

Location of a waste water treatment plant often contributes to eutrophication problems. Discharging treated effluent downstream from a lake removes nutrients and other materials in this waste water from the lake but may contribute to downstream problems. Locating the plant on an upstream tributary might provide for some nutrient assimilation before the waste stream enters the static water. Discharge of waste waters immediately upstream from, or directly to, a lake is the least desirable of alternatives.

Runoff from mismanaged lands carries large quantities of sediments and nutrient-rich top soils and fertilizers. Highway construction can leave extensive areas open to erosion for long periods of time. Similar situations occur in suburban residential developments where the land is stripped for sub-dividing.

Industrial plant locations can create many problems because wastes from some industrial sites are direct sources of nutrients. Frequently

Plate 1. Canoeing over calm, clear waters is a recreational pursuit made more enjoyable in unblemished surroundings.

land fills are economical methods of obtaining new acreage in congested areas. Industrial sites often do not include sufficient space for expansion or a waste water treatment facility.

Financing sewer systems to intercept waste waters from waterfront properties, especially in recreational areas, can be a problem because of the high per capita costs. Ground water tables near the surface can complicate the development of sewer and other drainage facilities. In hilly regions, impounded waters have very irregular shorelines and this too complicates sewer development. Increased lake frontage must be covered to adequately intercept the waste waters, and more pumping stations are required for the varied elevations. In many of these situations, the practical alternative seems to be individual septic tanks. Residences may be positioned so close to the lake that it is impossible to develop a sufficiently large tile field to prevent seepage to the lake. Placement a couple of hundred feet from the lake might reduce nutrients entering the lake since many critical nutrients are adsorbed to the soils. Eventually the soils may become saturated with nutrients and then nutrients may again seep to the lake. Preserving and restoring our lakes may well depend more upon good, practical land zoning than upon the more frequently considered nutrient removal or control aspect. Obviously people cannot be barred from the lake. If they were, its value would be reduced, but a lake destroyed by indiscriminate use is always a possibility.

Biota convert dissolved nutrients to settleable organic solids in the lake basin and a portion of these is incorporated in the bottom sediments. Nutrient additions can increase biological productivity and sedimentation. The factors contributing to a lake's aging, and eventual death, function in unison and as a composit are termed eutrophication.

Regulating Factors

Life in waters is influenced by water temperatures, dissolved oxygen, pH, color, turbidities, total dissolved solids, total alkalinities, nutrients, mineral composition, concentrations of heavy metals and concentrations of pesticides or other toxicants. Maximal values, and in some cases minimal values also, of these constituents often create an environment that becomes intolerable to particular organisms and will limit their production or interfere subtly with physiological processes that in turn reduce their ability to compete with others within the environment.

A waterway can be termed a living thing, a thing of energy, of movement, of change. It may be harnessed and made to do useful work but it struggles when an attempt is made to confine it. It is a living thing also because of the life within such an environment. A waterway must have certain physical-chemical qualities before a bountiful life will develop. There must be a plentiful supply of oxygen to support life, a virtual absence of biochemical oxygen demanding substances, a pH that approaches neutrality or is slightly alkaline, and a temperature amenable to organism reproduction and the continuation of various life stages of the organisms present.

A food web is established that ranges from the smallest to the largest organisms in the aquatic community. The natural land drainage furnishes the basic food material in the form of humus extracts, organic particulate matter, nitrogen and phosphorus and other essential nutrients, and various organic salts leached from the soil. Bacteria and algae begin the cyclic process by their ability to convert these materials to food for growth and reproduction. Single-celled protozoa live upon the bacteria, many-celled rotifers live upon the protozoa, and the more complex invertebrates can use both algae and microscopic animals as food. Ultimately the food web is consumated in various species of fish within the aquatic environment and these become the dominant organisms.

Plate 2. Sludgeworm eggs with embryos.

Competition for food and space is encountered by each individual organism within the aquatic habitat. Many organisms are adapted for life in riffles or in pools, upon a rubble substrate or in the soft mud where they burrow and live in tubes. The reproductive potential for each species is much greater than the number required to fill their niche in the aquatic society. However, natural mortality, predation, and the fact that only a given number of organisms can exist in one locality makes life in such a stream a true survival of the fittest. The natural conditions for existence for a given species form a constraining barrier to species distribution. Competition among organisms for food, space and other necessities of survival produces a natural community that is characterized by a great many different species with relatively few individuals representing any given species in the community. When conditions for existence deteriorate because of some types of pollution, predaceous and other species are eliminated. When an abundant food supply is present, those remaining species, which are reduced in number, will flourish and multiply in great numbers and may be a nuisance to man in his use of water.

Ecology

In our present vocabulary the term "ecology" is very common. It was not always thus. Ecology was born near the turn of the twentieth century. It came into being with a host of great names in biology, including those of Victor E. Shelford, Stephen A. Forbes, Henry B. Ward, R. E. Richardson, E. A. Birge, Chauncey Juday, and others. The science flourished as a period of observational biology and great strides were made in a comparatively short time in exploring and explaining in general terms the phenomena of both land and water.

As scientific knowledge and methods advanced, the generalists gave way to the specialists, and research was directed toward the intricate parts of the whole. The science of ecology relates these parts and seeks to uncover the subtle mechanisms of interdependence that maintain the life system.

Now the word "ecology"—unknown to all but a scientific few a quarter of a century ago—has become a dinner-table word. It is of a timely interest with the occurrence of the rapid environmental changes. The question of the day is: "How do we fit the human organism into his environment so that each can coexist in harmony and in full respect for those things that, if altered, may result in destruction of all?"

Steven A. Forbes in 1887 noted the complexity and interrelationships of organisms through community studies in water quality explorations. He concluded, "If one chooses to become acquainted with the black bass . . . he will learn but little if the limits himself to that species."

Forbes further called attention to the close community of interest that exists among species with the reasoning that to exist a species' birth rate must at least equal its death rate and that when a species is preyed upon by another, it must produce regularly an excess of individuals for this destruction. Forbes went on to say that on the other hand the dependent species must not appropriate, on the average, any more than the excess of individuals upon which it preys.

Pollution

Another dinner-table word with no official or universal definition is the term "pollution." Webster's Third New International Dictionary states that to pollute is to make unclean or impure, to defile, or to desecrate. Reduced to its simplest definition, pollution is the addition to water of any matter that can interfere actually or potentially with a reasonable water use. Interference may take the form of actually denying the water use or of simply making conditions less desirable for the use.

Pollutants alter detrimentally the physical, chemical, or biological properties in water for a present or potential water use. They may be

Plate 3. An open dump contributes to air pollution and is an aesthetic insult.

actually or potentially harmful or injurious to the public health or welfare; to animals, wild or domestic, aquatic or others; or to plants that are important to man. Pollution relates both to the quality and quantity of the waste. A given quantity of a substance introduced into a particular volume of water will result in a concentration of the particular substance. The concentration or quality is often a measure of the immediate degree of harm and the quantity of the substance introduced is an accurate measure of the waste's potential to pollute.

Pollution includes matter that floats, settles, remains suspended for a time, is dissolved, or that is altered biologically or chemically to become harmful. Some pesticides, heavy metals, and radionuclides undergo a phenomenon known as biological magnification within the water environment. A classic example of biological magnification is that of the insecticide DDD, which was introduced into Clear Lake, California, in 1949, 1954, and 1957 to control the Clear Lake gnat, a nuisance organism to lake shore inhabitants. Following the latter chemical applications, western grebes were found dead along the lake shore. Subsequent investigations revealed that the insecticide, applied at a concentration of 0.02 parts per million parts of water, had been taken up and accumulated in the microscopic waterborne plants and animals with a concentration of 5 parts per million (250X). Fish that ate the microscopic organisms concentrated the DDD in their fat to levels that exceeded 2,000 parts per million (100,000X over the water concentration). Grebes, which are diving birds, fed on the fish and died. The highest concentration of DDD in grebe tissue was 1,600 parts per million.

A similar situation exists with mercury pollution. Fish, in a number of waters, have accumulated mercury through the food chain so that the eating of too much of their flesh may be a hazard to health. Algae have been found to concentrate arsenic by a factor of 2,000 and lead by a factor of 40,000. Radionuclides have been concentrated by aquatic organisms by a factor of 200,000 times.

The environment has received belated, wide-spread publicity and public emphasis in the past few years. In its first Report to the President, the Council on Environmental Quality stated that "Historians may one day call 1970 the year of the environment." Water uses must be protected for the benefits of public health, including municipal water supplies; recreation, including boating and water skiing; swimming and sport fishing; aesthetic enjoyment; commercial fishing; agriculture; and industrial water supplies.

Society's Goal

The goal toward which this generation must exert its combined and coordinated energies must be to leave to posterity an environment that is aesthetically more pleasing and physiologically more healthful than the one that now provides us abundant life.

2

Environmental Insults

MAN daily insults the air, land, and water environments in which he lives. The smoke and chemicals billowing from a discharge stack or the sometimes colorful effluent coming from a sewer each contribute a load of pollutants to the receiving environment. When such pollutants are degradable, the receiving environment must expend a portion of its latent, and often renewable energies, in the degradation process. This process of degradation reduces the effectiveness of the environment to serve man in other ways. When pollution is of a repetitive rather than of an ephemeral nature, environmental degradation continues and the natural processes of recovery are prevented from fulfilling their cleansing actions.

Definition

Environmental insults may be defined in a number of different ways. Perhaps the simplest of these is to classify them as visible or nonvisible. The visible insults of the water environment include the sludges, silts, oils, and other rejectamenta from the manufacture of articles of commerce or from the waste barrels of civilization. The non-visible insults would include certain inorganic or inert materials that are permitted to enter the receiving watercourse. Each of these has its distinctive and ascertainable effect upon the water and the plant and animal life that reside therein. Heat pollution also can be termed a nonvisible insult as can other pollutants such as acid mine drainage, pesticides and other poisons, and fertilizing nutrients that stimulate biologic production to excess. The action of sublethal levels of some otherwise toxic pollutants is insidious in that physiological changes are produced within the aquatic organism that may not kill directly but may interfere or change the physiology of reproduction to an extent sufficient to eliminate the species from the particular waterway.

Aesthetic Qualities

The type of environmental pollution that is most observed by the citizen is that which can be seen either casually in passing or by inspection with the unaided eye. This type of pollution becomes an insult upon the aesthetic quality of the environment.

Water that should be a source of tranquil, aesthetic enjoyment often becomes a defiled conveyor of civilization's wastes, and a refuge for biological pests and nuisances. The National Technical Advisory Committee on Water Quality (Anon, 1968) addressed itself to aesthetic values with these words: "It is not surprising that water has occupied an important position in the concerns of man. The fate of tribes and nations, cities and civilizations has been determined by drought and flood, by abundance or scarcity of water since the earliest days of mankind.

"Artists have reflected man's fascination with water. Literature and art of a variety of cultures dwell upon brooks, waves, waterfalls, and lakes as superlatives among the delights of the environment.

"Aesthetically pleasing waters add to the quality of human experience. Water may be pleasant to look upon, to walk or rest beside, to contemplate. It may provide a variety of active recreation experiences. It may enhance the visual scene wherever it appears, in cities or wilderness. It may enhance values of adjoining properties, public and private. It may provide a focal point of pride in the community.

"The appearance of pollution and the fear of pollution reduces aesthetic value; the knowledge that water is clean enhances both direct and indirect aesthetic appreciation."

Lake Tahoe is the recognized jewel of the West and Mark Twain eulogized its aesthetic uniqueness with these words: "When the boat drifts shoreward to the white water and he lolls over the gunwale and gazes by the hour down through the crystal depths and notes the color of the pebbles and reviews the finny armies gliding in procession a hundred feet below. . . ."

A report on water pollution in the Missouri River stressed the great value of relaxation and mental well-being achieved by viewing and absorbing the scenic grandeur of the great and restless Missouri. Many people crowd the "highline" drives along the bluffs to view this mighty river to achieve a certain restfulness from the proximity of nature.

Conversely, Porterfield (1952) listed ". . . neuroses caused by noxious odors from polluted streams . . . ." among the effects on man from severe water pollution. Headaches and nausea are not uncommon complaints from those who live by algal laden waters, when the algal mass floats and decomposes in the hot sun and pigpenlike odors permeate the gentle breezes along the leeward shore.

The Water Quality Act of 1965 provided for the establishment of water quality standards for interstate waters. Under the terms of this

Plate 4. Acid mine discharges kill natural stream bed organisms. Note acid polluted stream bed on viewer's left compared to relatively unpolluted stream bed on viewer's right.

Act, the States assigned applicable uses to the individual interstate waters and adopted standards of quality to ensure that those uses would be protected. Subsequently, these standards totally or in part were approved by the Secretary of the Interior and became Federal-State water quality standards subject to the provisions of the Act. The purpose of water quality standards is not only to maintain, but also to enhance water quality throughout the Nation.

In their standards, each of the States adopted minimum water quality criteria applicable at any place at any time. Many of these minimum criteria relate specifically to maintaining the aesthetic quality. These minimum criteria specify that surface waters should be free from substances attributable to waste discharges that settle to form objectionable deposits; that produce objectionable color, odor, taste or turbidity; that are toxic to humans, fish and other animal life, and plants; and that float as debris, oil, scum, and other matter.

Quality Constituents

The pollution of the water aesthetics involves the defilement with at least a dozen discrete water quality constituents. It may be helpful to consider each of these separately within the context of their particular cause and effect relationship.

A. DEAD FISH

When fish die in large numbers at one time, it is usually a sign of an unnatural phenomenon within the aquatic environment. Fish die of old age like all other animals but usually the number so afflicted at any one time is so small that they go unnoticed. Fish populations become afflicted with death-dealing diseases or parasites but such is often confined to a single species of the total population at any given time. When several species involving several age groups are killed, the cause is often attributable to a catastrophic spill or discharge of a toxic compound, a drastic temperature change that traps fish in a lethal environment, or a reduction in the dissolved oxygen to levels that induce mortality. Reduced dissolved oxygen can be caused by the decomposition of organic materials from waste discharges, from the die-off of an abundant crop of algae or rooted aquatic plants, or the insidious conditions associated with winter kill under ice cover in northern climes.

Fish are significant indicators of water quality. Except for potential bacterial hazards, there is a general concept that a water which supports an ecologically balanced fish population is suitable also as a domestic water supply. The destruction of fish not only indicates a severe problem occurring in the aquatic environment, but also reduces a natural

Plate 5. A dramatic visible indication of an environmental catastrophe.

resource of recreational and often economic value. And dead fish offend the aesthetic of sight, as well as the sense of smell on a hot summer day.

The Environmental Protection Agency (EPA) publishes an annual Fish Kill Summary, which is a statistical listing of the reported number of fish killed by stream, State and waste source. The EPA has accelerated its program of reporting and responding to significant fish kills. A facet of this program was the development and publication of a leaflet on the technical aspects of fish mortality investigations. The purpose of this accelerated program is to more specifically determine the cause of fish mortalities and to permit abatement of their causes through appropriate actions. The identification of the cause of a fish mortality often involves rapid and precise investigation, highly sophisticated analytical testing, and a generous mixture of art sprinkled with experienced judgment.

B. FLOATING SOLIDS

Like dead fish, floating solids are a visible evidence of pollution or of a disregard by man for nature's unblemished beauty. Depending on their origin, floating materials may or may not offend the aesthetic of smell, or serve as a haven for mosquitoes, flies or other nuisances. Floating solids may accumulate as the rejectamenta from a passing motorist or bicyclist, or waterside stroller. The beer can, child's boot, paper sack and glass bottle are examples of the wanton toss. Why is it that the flowing stream is such an attractive receptacle for the empty container?

Floating solids may come from other sources that can affect the water quality more severely than discarded trash. Such solids may be attributable to discharges from the manufacture of an article in commerce, from odorous sludges that are carried to the surface ephemerally by gases of decomposition, or from accumulated living and decaying vegetation.

Solids from domestic and industrial wastes can and will be controlled through adequate waste treatment and the better operation and maintenance of waste treatment facilities. The EPA is now accelerating its program of plant operator training and is offering technical assistance to the States to enhance the operation and maintenance of sewage treatment plants.

The control of the discarded beer can, paper sack and glass bottle must be carried out through an accelerated educational program, originating in the schools, and a more effective enforcement of local litter laws. Stream clean-up days should become routine. Through local education and leadership, a sense of pride and protection must be instilled in people in their local waterways.

C. SETTLEABLE SOLIDS

Solids may be suspended in water for a time, and then settle to the bed of the stream or lake. These settleable solids discharged with man's wastes may be inert, slowly biodegradable materials, or rapidly decomposable substances. While in suspension, they increase the turbidity of

Plate 6. An insult to a waterway with otherwise excellent aesthetic potential.

the water, reduce light penetration and impair photosynthetic activity of aquatic plants, and make a sparkling clear water a murky, liquid mass.

Solids in suspension are aesthetically displeasing. When they settle to form sludge deposits on the stream or lake bed, they are often much more damaging to the life in water, and they retain the capacity to displease the senses. Solids, when transformed to sludge deposits, may do a variety of damaging things: They blanket the stream or lake bed and destroy the living spaces for those bottom associated organisms that would otherwise occupy the habitat. When of an organic and therefore decomposable nature, solids use a portion or all of the dissolved oxygen available in the area. Organic materials also serve as a seemingly inexhaustible food source for sludgeworms and associated organisms. Thus an assemblage of burrowing worms replaces the larval stages of caddisflies, mayflies, dragonflies, hellgrammites and other organisms that add ephemeral pleasures to those who take the opportunity to observe them, and marvel at their delicate features, during their individually brief sojourn as adults on earth.

The minimum water quality for interstate waters, as prescribed by the Federal-State water quality criteria standards, specify that such waters are to be free from all objectionable solids that interfere with designated uses. The Federal Water Pollution Control Act recognizes the primary responsibility of the States to maintain water quality and enforce water quality standards within their individual boundaries. There are certain provisions when the Federal government may take actions to abate pollution and enforce compliance with the water quality standards.

D. COLOR

Water is the most aesthetically pleasing in its natural color. The pea-soup appearance of a blue-green algal scum; the red-paint color from the red *Euglena* or from *Oscillatoria rubescens;* the dull brown color from a diatom bloom; the brillant red, green, and purple hues from textile dye wastes; the dead red color imparted by acid mine wastes are all aesthetically displeasing. Color is imparted to water from the soil through which it flows, from an overabundance of an aquatic crop that is stimulated perhaps as an indirect effect from the fertilizers present in some forms of pollution, and from direct pollution. In addition to aesthetic impairment, color reduces light penetration, which in turn affects the physiological responses of aquatic life.

E. SOLID WASTES

For the purposes of this discussion, solid wastes are defined as the masses of discarded materials, commonly referred to as dumps, that are deposited adjacent to or in the flood plain of waterways. The deposit of refuse matter of any kind or description whatever into the water or on the bank of any navigable water or on a bank of a tributary thereof, where the refuse is liable to be washed into the navigable water, is prohibited by the River and Harbor Act of 1899. The courts have traditionally given a liberal interpretation to the kinds of matters that may impede or obstruct navigation within the meaning of this Act, so that floating debris, siltation, or other small objects, when washed into the water regularly and in sufficient quantity, have been found to violate this provision. The River and Harbor Act is administered by the Corps of Engineers; however, anyone may request the United States Attorney to prosecute under this Act.

Presently there is public concern of considerable magnitude about such disposal practices. There is a general tendency for odd bits of shore-deposited trash to find their way into the waterway. An occasional semi-floating mattress or the remains of a discarded doll is not a pleasing sight to the boating public.

F. OIL

Pollution by oil out of control can occur almost anywhere at any time. Oil slicks on water seem to have an irresistible attraction for water birds. Once a bird alights on the oil mass its feathers become matted and oil soaked. The almost inevitable result is death by drowning through loss of buoyancy, by toxicosis from ingested oil, or from exposure caused by

Plate 7. Construction site siltation harms both land and receiving waterway.

loss of body heat insulation, or, unable to fly, the birds may slowly starve to death or be eaten by predators.

Successful treatment of rescued birds is extremely difficult. A month after oil was spilled by the TORREY CANYON, The Nature Conservancy in London reported that 7,000 birds had been rescued and treated but that only a few hundred lived.

When surface feeding fishes swim into the floating oil, their bodies and gills become coated. If death does not result from such contacts, their flesh absorbs the taste and odor-producing fractions of the oil, rendering them unfit for human consumption for a long time afterward.

As an oil mass moves landward, toxic oil fractions can bring death to both larval and adult forms of invertebrate marine life that inhabit the shallow, near-shore areas. Marine life, valuable to man as a food resource, may be totally destroyed or, at the least, is likely to acquire disagreeable tastes and odors from the oil. Beds of seaweeds, valuable as a food or industrial material, can be totally destroyed by the oil.

Finally, as the oil hits the shorefaces and collects in harbor or port areas, it blankets everything in its path. The usefulness of beaches for recreation suddenly ends. Navigational and fire hazards are created in harbors, ports, and marinas. Shorefront properties are despoiled, and the air reeks with the fumes.

In less heavily affected areas the odor may be less, but grime and stain abound. Snow-white cruisers and picturesque sailboats show a dark smear at the waterline; small children after playing on the beach come home with oily feet; swimmers are coated with oil patches which cling to their skins and mat their hair. Removal requires thorough scrubbing with detergent and kerosene.

The Federal Water Pollution Control Act prohibits the discharge of oil into or upon the navigable waters of the United States, adjoining shorelines, or into or upon the waters of the contiguous zone in harmful quantities. Liabilities have been established for failure to notify the United States Government of such a discharge by the facility discharging, as well as for violation of the Act.

G. TASTES AND ODORS

Most waterworks officials consider algae to be the most frequent cause of tastes and odors in water supplies, with other types of decaying vegetation second in importance. Decay or decomposition is brought about by fungi and bacteria, including the actinomycetes. The odors that are produced through the activities of fungi and bacteria may be either from the intermediate products formed during the decomposition or from special substances that are synthesized within the cells of microorganisms. The latter appears to be true in the case of the actinomycetales. Tastes and odors that have been related to various algal genera include such sensations as bitter, metallic, slick, sweet, fishy, grassy, musty, septic, nasturtium and cucumber.

Algae are not the only cause of organoleptic sensations; industrial wastes are a contributor in many areas. The EPA currently is conducting a study in such an industrialized area where a large number of complex organic compounds are contributing to serious taste and odor problems in the receiving water supply. Investigative and analytical techniques to identify contributing compounds and their sources are sophisticated and complex. As many as 300,000 gallons of water are pumped through a special, large carbon filter. Later the organic material is extracted from the carbon and then the process of individual compound identification begins through sophisticated organic chemistry analyses. Identified compounds are tagged to specific industrial waste outfalls through similar techniques.

Fish and shellfish absorb off-flavoring materials from the water environment and this produces great concern among the fishermen. Fish and shellfish products cannot be marketed or are reduced in value as a result. Studies by this Agency have linked a change in the degree of off-flavor in fish flesh to particular river reaches that receive discrete waste sources.

Fish flavor testing is done by placing unaffected fish in holding nets both upstream and downstream from a suspected pollution source. After five days, the fish are removed, filleted, quick frozen, and sent to a professional taste testing panel where individual fish flavors are rated against control specimens. Fish readily absorb many of the wasted by-products of industry's contribution to civilization.

H. SLIMES

Upon the introduction of waste sugars, nitrogen and other nutritive materials into watercourses, biological slimes may develop to the extent that visible masses appear. These are woolly, slimy coatings on submerged objects or tufts and strands, sometimes 15 inches or more long, streaming in the current from their point of attachment. They vary in color from milky white in fresh new growth to dull grey-white, brown or rusty-red, depending on age, nutrition, and the type and amount of solids they entrap from the passing water.

Numerous problems arise from the presence of slime growths in streams. Where commercial or game fishing exists, drifting slimes may foul gill nets rendering them ineffective, interfere with fish hatching by coating fish eggs, and smother aquatic animals that serve as food for fish. Biological slimes and the materials they entrap, such as plant fibers, wood chips, and debris, blanket the stream bed and destroy the homes of organisms that compose the aquatic food web.

Plate 8. Biological slimes defile a stream and destroy a habitat for benthic organisms.

Biological slimes bring about a visually unpleasant stream. To the public, they are an obvious sign of stream pollution. Prolific growths destroy the recreational potential of the water, and interfere with one of the major public associated uses of water. Slimes, in floating downstream with the currents, may clog intake screens of power plants and other installations. In areas polluted by paper mill wastes, for example, slimes have a secondary effect. The stream slime community is composed of a variety of microorganisms that are held together as a mat principally by *Sphaerotilus*. Such interwoven mats entrap silt, sand, fibers and chips. The filamentous masses offer shelter and support for other organisms such as bacteria, protozoans, nematodes, rotifers and occasionally midge larvae. During the process of decomposition, or because of physical disturbance, mats sometimes as large as three feet in diameter "boil" to the water's surface in an unsightly foul-smelling eruption. These "boils" may settle at or near the point of origin or be carried downstream to areas where the flow velocity permits settling. Here, sludge banks are formed that give rise to anaerobic conditions with subsequent offensive effects. These sludge banks may be formed many miles downstream from the initial pollution source, and thus increase the stream reach affected by pollution.

I. ALGAE

Algae appear as floating scums; suspended matter giving rise to murky, turbid water or water having a "pea soup" appearance; attached filaments; and bottom dwelling types that may be confused with the aquatic vascular plants. Algae are found in every nontoxic aquatic habitat. When stimulated by abundant nutrients, sunlight and warm temperatures, algae multiply rapidly to become a nuisance to water users. Nitrogen and phosphorus are the principal nutrients that are added with waste waters that stimulate algal growths, but carbon, iron, and often trace elements are sometimes involved in stimulating these growths.

Much is currently written about "dying lakes", which are lakes that have much life left but that have been changed to the extent that they now give rise to prolific algal production. Much effort and many resources must be expended to enhance the quality of the lakes so afflicted and to conserve our other waters so that they will not rapidly attain that eutrophic state.

Plant nuisances may curtail or eliminate bathing, boating, water skiing, and sometimes fishing; perpetrate psychosomatic illness in man by emitting vile stenches; impart tastes and odors to water supplies; shorten filter runs or otherwise hamper industrial and municipal water treatment; impair areas of picturesque beauty; reduce or restrict resort trade; lower water front property values; interfere with the manufacture of a product in industry, such as paper; on occasion become toxic to certain warm-blooded animals that ingest the water; foul irrigation siphon tubes and trashracks; and cause skin rashes and hay fever-like symptons in man.

When present in great numbers, algae may give an unsightly blue-green or green appearance to the water, form a massive floating scum that obstructs navigation or impairs water uses, in decay produce noxious odors that drive people from the area, remove dissolved oxygen from the water when decomposing and kill aquatic life as a result, foul fish harvesting equipment and water intake devices and reduce the carrying capacity of water distribution systems. *Stigeoclonium, Oedogonium, Ulothrix* and *Cladophora* have been problems in irrigation systems where they have restricted flow in the canals, and fouled pumps and tubes. *Cladophora* has been a problem of great concern in Lakes Ontario, Erie, and Michigan where abundant growths have become detached through wave and wind action to be washed upon a beach where they decompose to make the area uninhabitable.

Blue-green algae have been severe nuisance problems, especially to those engaged in water oriented recreation in most eutrophic lakes. *Chara*, a branched erect alga that becomes encrusted with calcareous deposits giving the plant a rough surface, has become a problem in many lakes and ponds with a high alkalinity. Should the lake or pond bed be composed of a peat-type material, *Chara* can become detached from its moorings and bring substantial quantities of bottom with it when it rolls to the surface in 9-inch thick rafts that obstruct navigation,

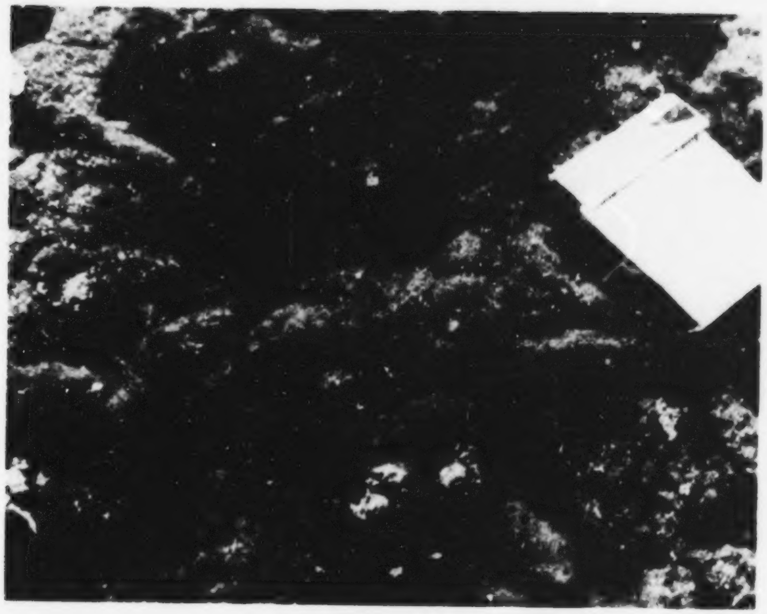

Plate 9. A nutrient-stimulated algal bloom, Lake Sebasticook, Maine.

destroy aquatic aesthetics, and emit vile odors. The author has witnessed dead tree stumps, with root systems that measure 20 feet in diameter, embedded in these floating *Chara* rafts.

J. VASCULAR PLANTS

There is beauty associated with the intricate design of aquatic vegetation. When such vegetation becomes too dense, beauty ceases and a nuisance has developed. Submersed aquatic plants can cause many of the nuisance problems described for algae. They are particularly troublesome to boaters, swimmers, and water skiers.

Like algae, aquatic vascular plants relish a liberal supply of nutrients. Most of the vascular plants have roots and many are able to take a portion of their needed nutrients from the soil in which their roots penetrate. Submersed plants must have sunlight following seed germination and during their active growth period. This restriction limits their distribution to that zone with a depth of about 20 feet in most freshwater bodies.

The depth of water determines the adjustment of aquatic seed plants into three principal categories. Emersed plants are those that occupy shallow water, are rooted in bottom mud, and support foliage, seeds and mature fruit one or more feet above the water surface. Cattails and rushes are familiar examples. Surface or floating plants generally grow in deeper water in front of (and oftentimes commingling with) the emersed plants. The larger floating plants are water lilies that may be rooted in the mud of the bottom and bear large leaves that float upon the surface. Submersed aquatic growths often form a belt or zone of herbage farthest from shore. The pondweeds are examples of this group.

K. SLUDGEWORMS, BLOODWORMS AND ASSOCIATES

"And the stream turned red like some giant brush had stroked the bottom with paint!" This is not rhetoric but was a complaint once filed. The cause of the problem was the red sludgeworms and bloodworms living happily in the rich sludge covering stream beds that received organic wastes. These organisms burrow in the sludge and use it as a food source. In so doing, they function as one component of a treatment system because after they have used the sludge it is a little more stabilized than before. Thousands of these creatures, individually no larger than the fine lead of a pencil, can live in a square foot of sludge-laden stream bed.

Sludgeworms live with their heads buried in the sludge and their tails waving in the current. When disturbed, they disappear into their burrows to reappear when the suscepted danger is past. In streams receiving pulp and paper wastes, this author has observed sludgeworms to form balls that may attain the size of a clenched fist.

Midge larvae are shorter and thicker than sludgeworms and construct tubes around them through which they circulate the water to obtain food, as well as take opportune advantage of all available oxygen. Many are blood red in color. They hatch into hordes of principally non-biting adults that resemble large mosquitoes. During their swarming period they may become a very noticeable nuisance around homes and in their habit of getting into ears and nasal passages of children. They have been known to stop traffic on roadways because of the denseness of the flying masses.

L. TOXIC STREAMS

There is no pleasure in an environment without life. The water may be crystal clear, and it may portray a tranquil scene in riffles and pools, but without life, water is dead. Toxic substances kill aquatic life, either a few at a time if the substances are dilute or many at once if the toxic materials are strong. In either case, the reach of water receiving these materials is rendered useless for many water uses.

Control

The purpose of this chapter is not to discuss in detail the control of those things that defile the aesthetic properties of water. Suffice it to state that the implementation of the following would make possible the giant step towards control's success:

1. A universal citizen awareness and concern about the problem with an innate desire to make conditions better tomorrow than they were today.

2. Community sponsored lake and stream clean-up campaigns periodically undertaken.

3. An evaluation of local litter laws coupled with a meaningful enforcement program.

4. Accelerated water pollution control efforts to ensure adequate treatment of all wastes to meet water quality standards and protect receiving waters for the many uses they perform.

Postscript

If a postscript is to be stated in defense of water aesthetics,
It should be sufficient to pause for a moment and recall
The crystal clear depths of Lakes Tahoe or Crater;
The shimmering waters of a Bois Brule, or the grandeur of a waterfall.

Must one in all honesty defer to memory alone
To visualize a stream or a lake unblemished by human deeds,
Where finny friends, and caddis fly, and crayfish alike,
Without stress from pollution or unencumbered by trash, conduct
  nature's needs?

3

Controlling Environmental Insults

Some of the Problems

IT has been estimated that 15,000 spills of oil and hazardous materials occur annually in U. S. navigable waters. Presently 75 percent of these spills involve petroleum products. The potential for oil spillage is expected to triple over the next 30 years. This potential is related to the projected increased demand for petroleum products.

The major effects of spills of oil and hazardous materials are injury or death to aquatic life and aesthetic and economic damages to beaches, boats, and shoreline property. Essentially all navigable and coastal waters of the Nation are vulnerable to oil spills because of the wide dispersion of oil and petroleum product transport, storage, refining, and use. Many of the Nation's non-navigable surface waters and groundwaters are subject to oil spill damage because of pipeline breaks, tank truck accidents, rupture or leakage from gasoline stations and other small tank storage facilities, and the deliberate dumping of waste oil.

In 1970, 25 million cattle were marketed from about 184,000 feedlots, each holding over 1,000 animals at a time. Nearly 9 million cattle were marketed from 350 feedlots. The daily manure production averages 60 pounds per head for each 1,000 pounds of live weight animal. An estimate of the national production of livestock manure in the United States is 2 billion tons annually. On a pound-for-pound basis, the potential for phosphorus pollution to the receiving waterway from a steer and a human is comparable. Winter runoff concentrations from a cattle feedlot have reached as high as 750 mg/l phosphorus and 2,000 mg/l ammonia nitrogen. Runoff can be toxic to aquatic life, remove needed oxygen from the water, and supply food for the development of nuisance biological pests.

Sediments produced by erosion are the most extensive pollutants of surface waters. It has been estimated that loadings of suspended solids reaching our waters are at least 700 times the loadings from sewage discharges. The dirty brown or grey appearance of a river or reservoir after a rainstorm is due to sediments washed in from crop land, unprotected forest soils, over-grazed pastures, or the bulldozed "developments" of urban areas. The presence of sediments generally increases the cost of water purification and reduces the value of water recreation. Nutrients adsorbed on sediment particles contribute to undesirable conditions in standing waters. Erosion is a serious problem on at least 300,000 miles of the Nation's stream banks and along many of the 470,000 miles of rural and secondary roads. Over 1 billion tons of sediment reach the rivers of our country each year. Approximately ten percent of this quantity is contributed by erosion from lands undergoing development or highway construction. Sediment quantities in streams flowing from urbanized drainage basins vary from approximately 200 to 500 tons per square mile per year. In contrast, the urbanized areas have quantities varying from 1,000 to 100,000 tons per square mile per year.

In some areas, serious water quality degradation has occurred as a result of runoff from irrigated lands. Water returned from irrigated areas usually has a much higher concentration of dissolved solids than does stream flow because the diverted water leaches additional solids from the fields, and because evaporation from the soil and transpiration by the crops concentrate the dissolved solids into a smaller flow of water. Particular problems have been encountered in the Colorado River Basin because of the increased salt content in irrigation return flows.

Both active and abandoned mines pose problems of water pollution. Acid mine pollution is a well-publicized result of mining activity and contributes 4 million tons of pollutants annually. There are about 12,400 miles of stream that are significantly affected by mine pollution in the United States. Most of these are degraded by coal mining operations, but mining for copper, lead and zinc, uranium, iron, sand and gravel, phosphates, and other minerals are important factors. Stream degradation by mining activities in the Appalachian coal region accounts for 84 percent of the stream miles polluted by mine wastes. Mine pollutants include such dissolved constituents as acid, iron, copper, arsenic, cadmium, nickel, sulfate, phosphate, radioactive minerals, suspended sediments, and colloidal iron.

Sediment yields from strip-mined areas have reached nearly 30,000 tons per square mile annually. This is 10 to 60 times the amount of sedimentation from agricultural lands. At this rate the two million acres of strip-mined land in need of reclamation could be a source for 94 million tons of sediment a year.

In addition to mine drainage, refuse piles, and tailing ponds, washery preparation residues are also important indirect sources of pollution from mining. For many minerals, such as phosphates, the pollution from

Plate 10. Uncontrolled erosion in a housing development is the genesis of a waterway's sediments.

processing operations exceeds that resulting directly from the mining operation. The pollution from coal mines in Indiana and Illinois, for example, arises primarily from refuse piles, tailing ponds, and preparation plants. No national estimates are available that show the volume or related importance of pollution from these sources.

Industry is a very big polluter of water and water is one of this Nation's most valuable resources. The waste water discharges from the processing of food, textiles, paper and chemical products, petroleum and coal, rubber, primary metals, and machinery and transportation equipment exceed 14 trillion gallons annually. By comparison the waste water volume of domestic sewage from the population of the United States served by sewers is slightly more than 5 trillion gallons. Waste water volumes from two industries only, chemical and allied products and primary metals, which include glass furnaces and steel mills, exceed that of domestic sewage by a substantial margin. The great preponderance of American industrial water use, as measured by waste water discharges, occurs in the Northeast, North Atlantic, the Great Lakes areas, and the Ohio River Drainage Basin.

The April 1971, United States Department of Commerce publication on "Water Used in Manufacturing," reported 241,000 water-using industries. Of these, 9400 or 3.9 percent consume 20 million gallons or more of water. About 80 percent of the water used by industry is fresh; the remainder is brackish. Of the industrial waste waters discharged, 4.3 trillion gallons or 31 percent were treated prior to discharge. Over one-half of the waste water volume is from four major water-using groups and these include primary metals, chemicals and allied products, paper and allied products, and petroleum and coal products.

The above are but some examples of the many forms of pollution entering the Nation's waterways. The control of these environmental insults must be a cooperative and integrated effort on the part of the individual citizens, organized citizen groups, local governmental units, small business managers, corporate industrial executives and production managers, State and Federal Governments, and the legislators.

Citizens Groups

The growing interest of individual citizens and citizens' groups has been a major factor in causing government and industry to move more rapidly in the implementation of pollution abatement and control programs and in devising a successful recycling program in the Nation's battle against solid wastes. Litter continues to mar our Nation's highways and city streets, our parks, and public buildings. Anti-litter campaigns and the creation of local reclamation centers have focused public attention on the potential value of recycling these waste products. While the total number of bottles, cans, and paper collected and separated at home and local recycling centers may constitute only a small percentage of the total produced, this is at the very least a beginning toward a solution of a very large problem.

Unfortunately, many false hopes have been raised about the likelihood of large scale recycling as a solution to our solid wastes problems in the immediate future. There will have to be some fundamental and long-ranged changes in our life styles and in the structure of our economy to achieve such a goal. Too often citizen groups have rushed into setting up local reclamation centers only to find that poor planning, lack of existing markets and a tapering off of voluntary participation force them to close. Having started with high expectations, many people have become discouraged about the potential of recycling. The publicity and glamourization of recycling has also had a negative effect on efforts to construct less glamourous types of conventional disposal facilities, which are needed now.

Education Needs

There is still a tremendous need for education on waste reduction of all kinds: Waste of electricity, gasoline, and other forms of energy resources; waste of water and food; waste of paper, metals, minerals, glass and our other natural resources. The Environmental Protection Agency is working with the Office of Consumer Affairs, the Department of Housing and Urban Development, and other Federal agencies to launch an active public education campaign for the reduction of consumer wastes. Similar programs on waste avoidance for business, industry, and State and local governments are likewise urged.

Several environmental education programs recently have been launched by the Federal Government. In October 1971, the Environmental Merit Award Program, now administered by the Environmental Protection Agency and supported by the U. S. Office of Education, was initiated. This program provides national recognition to successful student environmental project. It has already involved over 2,000 high schools across the country.

The National Park Service has done impressive work in developing curriculum materials through the National Environmental Education Program. Study sites have been established on Federal park lands and the program is now being extended to natural and man-made sites, both public and private. As often as possible the environmental study sites are being located in or near major urban areas.

The Forest Service has established an effective teacher-training program. The program uses forest service field personnel to conduct environmental workshops for teachers from widely separated disciplines. The Department of Agriculture recently established an "Environmental Thrust" campaign to provide organizational and technical guidance to community projects in environmental quality.

A most significant Federal activity in the realm of environmental education was the Environmental Education Act of 1970, including the establishment of an Office of Environmental Education within the U. S. Office of Education. A National Advisory Council was appointed to oversee the implementation of the Act. Some 74 grants, totalling over $1.7 million, were processed during fiscal year 1971 and these supported a wide range of projects principally outside the context of formal education. These projects stress community-based environmental education and are focused on local environmental problems.

Citizen Action

As a result of this increased awareness and interest toward environmental cleanup on the part of the individual citizen, the question is often asked, "What can the average citizen do to protect and enhance the environment?"

Voluntary citizen organizations have long been a part of the way of life in the United States. Individuals with common interest in social, civic, cultural, religious, political, business and professional pursuits have united together in clubs, societies, associations, and groups to share their common interests. Thousands of such groups exist. Among them now are at least 3,000 conservation and environmental organizations. This number includes approximately 250 national and regional groups and about 400 State organizations. On the local community level, there are approximately 2500 organizations of individuals concerned about one or more conservation or environmental problems. In addition, there are uncounted civic, church, labor, business, youth, school, and women's groups that devote at least some of their efforts toward the solving of environmental problems.

Environmental organizations vary in size and range of activity. Some employ professional staffs. Some, especially on the local level, operate solely with volunteers. Some are concerned with a single issue while others are concerned with any and all environmental problems. While the scope and degree of their efforts vary, in total, they engage in a multitude of activities on behalf of a better environment. The groups work for water pollution control, cleaner air, noise control, better methods of solid wastes management, conservation of natural areas, preservation of wildlife, transportation reform, pesticide control, and sound resource management.

Plate 11. A stream-bank dump pollutes the receiving waterway for miles.

Such citizen organizations serve as the active articulate voices of a public which has become increasingly concerned about environmental quality. These groups fulfill a watchdog role. They exert a pro-environmental influence on public opinion, on the press, on industry, and on government. Through their individual concern and relentless prodding of industrial and governmental officials, these citizen groups mold and hasten actions that result in a better and cleaner environment. Through a stimulus from these groups, other citizens are motivated to join the crusade for environmental actions. It is most important, however, that these actions be directed toward achievable, technical accomplishments with a sound appraisal of the problem and various alternatives available rather than to be misdirected by emotional or political motives.

The planet earth serves as man's parlor and it should be treated with the same respect and thoughtfulness as the innermost sanctuary of one's dwelling. Each citizen should make it his duty to become informed regarding the problems of water pollution and its control, the alternatives of control actions, and the long-range water resource and waste water control management plans, founded on technical concepts and judgments, that have been developed for the area in question. Unless a citizen becomes well informed on these critical matters, his efforts may be unintentionally misdirected and impede rather than assist the development of a feasible control management program. A citizen can become informed on these matters by obtaining and reading technical and semi-technical authentic reports and by questioning government officials and technical experts who are working with the problems.

There are a number of actions a citizen or a citizens' group can take to foster the pollution control efforts. Examples of such actions would include:

1. Encourage industries and municipalities at all opportunities to adopt and implement pollution abatement or control measures.
2. Don't discard unwanted things in areas where they will receive inadequate disposal or where they will clutter the environment.
3. Don't litter; assist in picking up and disposing of litter that may have been discarded by others.
4. Promote through individual efforts, private organizations, or a community effort, all attempts to cleanse the environment of the rejectamenta of civilization and promote campaigns and educational programs to prevent contamination of the environment with such materials.
5. Support local and other governmental efforts in the adoption and implementation of realistic pollution abatement and control programs.

6. Support and encourage efforts to recycle waste materials into products of use to civilization.
7. For sake of economy and environmental preservation, use no more than the minimal amount that has been determined to fulfill the intended useful purpose of a given product.
8. Do not waste electricity, gasoline, and other forms of energy resources; water or food; and paper, metals, minerals, glass, and other natural resources.
9. Seek to influence government decisions to protect, preserve, conserve, and enhance environmental quality.
10. Remember always that a discharge valve cannot be shut instantly. To use currently available technology requires planning and construction. Often gigantic strides toward accomplishment of defined goals are made with small incremental positive steps taken in the right direction.

Strive to become an informed citizen regarding the current pollutional problems, the actions that have been taken to correct the problems, the facets of the problems that need yet to be corrected, the technology currently available for the correction of the problems, and the efforts being pursued by municipal, industrial, and governmental agencies that will result in problems correction.

The Role of Industry and Agriculture

Industries, municipalities, and agricultural enterprises have an obligation to society and to posterity to preserve all facets of the environment so that it may be used and enjoyed in an undiminished and undegraded condition by all who follow. Decision makers in these groups, therefore, have an obligation to plan pollution control actions far into the future to ensure that production changes can be accommodated without environmental degradation. Decision makers have an additional obligation to control present pollution and to promote programs that include the immediate use of pollution abatement and control technology that are currently available rather than await a legislative mandate or an action on the part of government, or by the courts, to force implementation of pollution control procedures. The decision makers in industry, for municipalities, and in other enterprises should take the forefront in pollution abatement and control.

The Role of Governments

The role of governments in the pollution abatement program is to investigate pollution damage and identify the causes, to research and support research directed toward the development of new and innovative treatment or control technologies, to demonstrate the feasibility of control technology, to adopt standards of performance and of environmental quality, and to regulate and enforce laws and regulations fostering treatment and control efforts. The first step toward a control measure is the identification and quantification of particular sources of pollution. This investigative procedure largely has been accomplished for those sources that are obvious. Likewise, the gross effect of various types of pollutants are generally known but research continues to determine the subtle effects of sublethal changes on the physiology of various life forms that inhabit the receiving waterways.

Research efforts to develop new, more effective, and less costly methods for pollution abatement and control will always be required. Likewise, the feasibility and technological reliability of developed methods must be demonstrated before they can be adopted fully by industry. The demonstration of environmental improvement techniques and management practices are also essential for the enhancement of environmental quality and these demonstrations have largely been lacking in the past. For example, we need to demonstrate on a field-scale level the reliability of certain eutrophication control measures before such measures can be adopted as tools in the control of the broad-scale eutrophication problem facing this Nation.

The governments must develop, adopt, and promulgate criteria and standards to define those levels of environmental quality that must be maintained by this society. Such standards further must be promulgated to define those limits on pollution that will maintain through time the necessary environmental quality.

Legislators must adopt laws that will permit appropriate actions and interactions among governments to insure the maintenance of adequate environmental quality. Following the adoption of such laws, the appropriate governments must be responsive in the development of mandated programs and in the enforcement of laws and regulations that may evolve from such legislative actions.

4

Legal Constraints

River and Harbor Act of 1899

The dynamic philosophy of legal constraints against water pollution had its genesis in the River and Harbor Act of 1899. This Act constituted the first specific Federal water pollution control legislation. Section 13 of the Act made it unlawful to throw, discharge, or deposit any refuse matter of any kind or description other than that flowing from streets and sewers and passing therefrom in a liquid state into any navigable waters. This section made it equally unlawful to deposit material of any kind on the bank of any navigable water or its tributary where the same shall be liable to be washed into the navigable water. The United States Army Corps of Engineers could grant permission for the deposit of any material that might otherwise violate the language of Section 13. The Department of Justice was given authority to enforce the provisions of the River and Harbor Act of 1899 as they pertain to water pollution. A statement within the penalty provisions provided that one-half of any fine collected for violation of this Act shall be paid to the person or persons giving information which shall lead to conviction. The provisions of the River and Harbor Act of 1899 have assumed major significance in the fight against water pollution in recent months and the United States Department of Justice has prosecuted a significant number of cases to abate water pollution under its provisions.

Early Water Pollution Control Legislation

The Public Health Service Act of 1912 contained provisions authorizing investigation of water pollution relating to the diseases and impairment of man. In 1924, the Oil Pollution Act was enacted to control oil discharges in coastal waters that might be damaging to aquatic life, harbors and docks, and recreational facilities. This Act made it unlawful for any person to discharge or suffer or permit the discharge of oil by any method, means, or manner into or upon the coastal, navigable waters of the United States from any vessel using oil as fuel for the generation of propulsion power or any vessel carrying or having oil thereon in excess of that necessary for its lubricating requirements.

Legislation was first enacted for the control and abatement of water pollution in some States in the late 1930's. As early as 1941, for example, additional enabling legislation was passed in Wisconsin for the purpose of controlling biological growths. It instructed the State Committee on Water Pollution ". . . to supervise chemical treatment of waters for the suppression of algae, aquatic weeds, swimmer's itch, and other nuisance-producing plants and organisms. To this end, the committee may conduct experiments for the purpose of ascertaining the best methods for such control. It may purchase equipment and may make a charge for the use of same and for materials furnished, together with a per diem charge for any services performed in such work. The charge shall be sufficient to reimburse the committee for the use of the equipment, the actual cost of the materials furnished, and the actual cost of the services rendered, plus ten percent for overhead and development work."

Federal Water Pollution Control Act

In 1948, the Federal Water Pollution Control Act was passed as Public Law 845 by the 80th Congress. It provided pollution control activities in the Public Health Service of the then Federal Security Agency and in the Federal Works Agency. The Act declared it to be the policy of Congress to recognize, preserve, and protect the primary responsibilities of the States in controlling water pollution, to support and aid technical research, to devise and perfect methods of treatment of industrial wastes which are not susceptible to known effective methods of treatment, and to provide Federal technical services to States and interstate agencies and to industries, and financial aid to States and interstate agencies and to municipalities in the formulation and execution of their abatement programs. Section 2 of this Act stated: "In the development of such comprehensive programs due regard shall be given to the improvements which are necessary to conserve such waters for public water supply, propagation of fish and aquatic life, recreational purposes, and agricultural, industrial, and other legitimate uses."

Comprehensive water pollution control legislation was enacted by the 84th Congress, which passed the Federal Water Pollution Control Act, Public Law 660, on July 9, 1956. The 1956 Act extended and strengthened the 1948 Act and was administered by the Surgeon General of the Public Health Service under the supervision and direction of the Secretary of Health, Education, and Welfare. The Act provided grants for State water pollution control programs and authorized the granting of Federal funds to any State, municipality, or intermunicipal or interstate agency for the construction of necessary treatment works to prevent the discharge of untreated or inadequately treated sewage or other wastes into any waters and for the purpose of reports, plans, and specifications in connection therewith.

A definition of comprehensive planning was contained in one of the recommendations of the National Conference on Water Pollution held in Washington, D. C., December 12 to 14, 1960. This recommendation stated:

> "Planning for the comprehensive development of each major basin or water resource area should be established as a fixed national policy. By comprehensive development we mean the application of integrated multiple-purpose design, planning and management which include the joint consideration of ground and surface waters, systematic conservation by water users, and the treatment and management of waters having substandard quality. Consideration of every appropriate technique would be a routine part of planning for such development.
>
> "Such planning insofar as feasible, should include consideration of all important industrial plant sites. An early and important objective should be a systematic program of flow regulation. State initiative toward comprehensive planning should be encouraged, and participation by all major interests should be encouraged. The objective should be one of eventually producing maximum total benefits from all economic and social use."

Further amendments to the Federal Water Pollution Control Act were signed into law on July 20, 1961 as Public Law 87-88, 87th Congress. The 1961 amendments improved and strengthened the Act by extending Federal authority to enforce abatement of pollution in interstate, as well as navigable waters. It provided that in the planning for any reservoir, consideration shall be given to inclusion of storage for regulation of stream flow for the purpose of water quality control, except that any such storage and water releases shall not be provided as a substitute for adequate treatment or other methods of controlling wastes at the source.

Water Quality Act of 1965

The Water Quality Act of 1965 established the Federal Water Pollution Control Administration within the Department of Health, Education, and Welfare. With the presidential reorganization plan effective on May 10, 1966, the Federal Water Pollution Control Administration was transferred to the Department of the Interior. The Water Quality Act of 1965 provided for the establishment of water quality standards to enhance the quality of all of the Nation's interstate and coastal waters.

In setting the water quality standards, the States were mandated to determine after public hearings the uses to be made of particular reaches of interstate water. Following this determination, criteria were to be adopted that would define the levels or ranges of bacterial pollution, dissolved oxygen, temperature, and other water quality constituents that would provide for these uses. In addition, the States were to develop and submit to the Federal Government a specific and enforceable implementation plan to meet the criteria that were established. These water quality standards have been submitted by the individual States and, on the whole, have been approved by the Federal Government. With this action, they became Federal-State water quality standards enforceable by either level of government with the individual States having primary responsibility for enforcement. Water quality standards represented a major step forward in defining the quality of water that would be acceptable to meet certain designated water uses. The prescribed water uses, developed through public hearing and participation of the public, were the result of direct involvement in water pollution control regulatory activities by the private citizen. The goal behind the water quality standards provision was that the quality of this Nation's waters shall be enhanced through implementation of appropriate treatment or control measures to abate water pollution. A further provision of the Water Quality Act of 1965 extended Federal enforcement powers and authorized Federal action when substantial economic injury results from the inability to market shellfish or shellfish products in interstate commerce because of pollution. A substantial effort was expended by the individual States, as well as the Federal Government, in responding to the mandate of this Act for the establishment of standards of quality on all interstate and coastal waters.

National Environmental Policy Act of 1969

A very significant piece of legislation was embodied in the National Environmental Policy Act of 1969, Public Law 91-190 of the 91st Congress enacted January 1, 1970. This Act created the Council on Environmental Quality in the Executive Office of the President whose responsibility it is to formulate and recommend national policies to promote the improvement of the quality of the environment. In addition, the Act provides for the development and filing of an environmental impact statement for any Federal action significantly affecting the quality of the human environment. The Environmental Impact Statements shall detail the environmental impact of the proposed action, any adverse environmental effect which cannot be avoided should the proposal be implemented, alternatives to the proposed action, the relationship between local, short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented. As a result of this Act, the Environmental Impact Statements filed by other Federal agencies related to the effects and potential effects of the designated action on the air, land, and water quality are reviewed in detail by the Environmental Protection Agency.

Water Quality Improvement Act of 1970

The Water Quality Improvement Act of 1970 was passed by the 91st Congress as Public Law 91-224 on April 3, 1970. This Act amended the Federal Water Pollution Control Act and changed the name of the Federal Water Pollution Control Administration to the Federal Water Quality Administration. A new and comprehensive section was added on the control of pollution by oil. This section prohibited the discharge of harmful quantities of oil into or upon the navigable waters, adjoining shorelines, or the contiguous zone of the United States. It provided that a person who is in charge of any vessel must immediately notify the Federal Government whenever any discharge of oil occurs and if he fails to do so he is subject to a fine of $10,000 or imprisonment for not more than one year or both. This Section provided a revolving fund to finance the removal of oil and other hazardous materials. In addition, the Water Quality Improvement Act of 1970 provided for the control of hazardous polluting substances and directed that such substances be designated that are dangerous to the public health or welfare when discharged into the navigable waters of the United States.

A Section was provided on the control of human body wastes from vessels and mandated the Environmental Protection Agency to promulgate standards of performance to control these wastes. In addition the Act provided that each Federal agency engaged in any Federal public works activity must comply with applicable water quality standards, as well as the purposes of the Federal Water Pollution Control Act.

Reorganization Plan No. 3, effective July 1970, transferred all Federal water pollution control programs to the Administrator of the Environmental Protection Agency. This independent agency, reporting to the President, has Federal jurisdiction over water pollution control programs, air pollution control programs, solid wastes abatement programs, radiological and pesticidal programs, and noise abatement. The Federal effort includes the granting of Federal funds for the construction of pollution treatment or control devices; technical support to State, interstate agencies, and other groups or individuals; regulatory and enforcement activities; and research, demonstration, and development of new or innovated processes for the control or treatment of waste products. The establishment and subsequent functioning of the Environmental Protection Agency provides a united front within the

Federal Government directed toward the purposes of prevention, control, or abatement of pollution or insults to the air, land, and water environments. The Environmental Protection Agency is organized with an Administrator and Deputy Administrator who direct the Agency's activities. Assistant Administrators are charged with responsibilities for air and water programs; categorical programs, including pesticides, radiation, and solid wastes; research and monitoring; general counsel and enforcement; and administration.

Federal Law

In the chronology of Federal laws to control water pollution, it has been a declared policy of Congress to recognize, preserve, and protect the primary responsibilities and rights of the States in preventing and controlling water pollution. Provision has been made for the granting of Federal funds for a number of special purposes. Federal funds on a matching basis may be granted to a planning agency at the request of a State for the purpose of developing a comprehensive pollution control and abatement plan for a basin. Such a plan must be consistent with applicable water quality standards and must recommend treatment works and sewer systems that will provide the most effective and economical means of waste water management. Grants may be made to States and interstate agencies to assist them in meeting the costs of establishing and maintaining water pollution control programs, including the training of personnel of public agencies. Substantial sums of money have been allocated also for grants to any State, municipality, or intermunicipal or interstate agency for the construction of necessary treatment works to prevent the discharge of untreated or inadequately treated sewage or other wastes into any waters and for the purposes of reports, plans, and specifications in connection with this program. These funds have been allocated on a matching basis with State funds.

Federal grants for research, demonstration, and development may be made to assist in the development of any project which will demonstrate a new or improved method of controlling the discharges into any waters of untreated or inadequately treated sewage or other wastes from sewers which carry storm water or both storm water and sewage, and to assist in the development of any project which will demonstrate advanced waste treatment and water purification methods. Further, such grants may be made to persons for research and demonstration projects for prevention of pollution by industry including, but not limited to, treatment of industrial wastes. Such grants must be approved by the appropriate State water pollution control agency and no grant shall be made unless it is determined that such project will serve a useful purpose in the development or demonstration of a new or improved method of waste treatment or pollution prevention and that such method shall have wide and general applicability for the industry or nation as a whole.

Provision has been made in Federal water pollution control law for technical assistance to conduct investigations and research and make surveys concerning any specific problem of water pollution confronting any State or community or industrial plant with a view of recommending a solution of such problem. The Federal Government is authorized to collect and make available through publication and other appropriate means information on water quality and water pollution control measures and to collect and disseminate basic data. Federal authorization has been provided also for the maintaining of field laboratory and research facilities and at the present time such laboratories are located in strategic locations within the ten regional offices of the Environmental Protection Agency. Provision has also been made for training activities both from the standpoint of training Federal personnel, as well as State and other personnel in water pollution, analytical, and management techniques.

The Federal agencies' enforcement prerogatives for water pollution abatement have historically been constrained by the language within the Federal Water Pollution Control Act. Federal actions to abate pollution may be taken when the health or welfare of persons is endangered in a State other than that in which the discharge or discharges originate. Federal actions may be taken also when requested by the Governor of any State or the State water pollution control agency when the health or welfare of persons is endangered in a State other than that in which the discharge or discharges originate. The Governor of any State may request Federal intervention to abate pollution of interstate or navigable waters when the health or welfare of persons is endangered in the requesting State from pollution arising therein. In addition, the Federal Government may take enforcement actions against violators of Federal-State water quality standards where such violations have not been corrected by the State authorities. Federal actions may be taken against polluters where substantial economic injury results from the inability to market shellfish or shellfish products in interstate commerce because of pollution.

The United States Department of Justice has undertaken prosecution of a number of water pollution cases in violation of the River and Harbor Act of 1899. In addition, the Corps of Engineers and the Environmental Protection Agency have been cooperating in the evaluation of permit applications for the discharge of industrial wastes as provided for in that Act. Essentially three alternatives are evident when a particular application is reviewed within the context of environmental damage. One alternative would be to recommend approval of the ap-

Plate 12. Wastes that must be treated to protect the receiving waterway.

plication as received. Another would recommend conditional approval based upon the implementation of a waste treatment or control program with defined and acceptable implementation dates that would bring the waste water discharge into compliance with water quality standards and general environmental acceptability. The third alternative is to disapprove the application as presented and request a resubmission that would detail a new program approach for waste water control or treatment.

Federal Water Pollution Control Act Amendments of 1972

Many of the past efforts to abate water pollution have not demonstrated dramatic and visible accomplishments. This has been due to a number of reasons not the least of which is the accelerating demand placed upon American industry to produce more products and an increasing number of types of products. The expanding population and the expanding industrial development have resulted in a dramatic increase in the pollution load upon the receiving waterways. Were it not for the substantial efforts toward pollution abatement that have been made by governments at all levels, industry, and the private citizen, water quality would be far worse than it is at the present time.

In a great many cases, unfortunately, these past efforts have kept pace only with increased production and have not served to clean up areas with a long history of pollution. The inability of past water pollution control efforts to demonstrate visible improvements in water quality has led to citizen demand for more stringent and more encompassing Federal legislation and involvement in water pollution control efforts. As a result of such public outcry for action, the 92nd Congress enacted on October 18, 1972, a series of very comprehensive amendments to the Federal Water Pollution Control Act.

In this legislation to form the basis of future Federal water pollution control efforts, it is the expressed national goal that the discharge of pollutants into the navigable waters of the United States be eliminated by 1985 and that the discharge of toxic pollutants in toxic amounts be prohibited. Further, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water is to be achieved by July 1, 1983. The legislation provides for a number of significant changes in Federal water pollution control laws and would extend and expand Federal authority in the control of industrial wastes, toxic materials, non-point source wastes and ocean dumping and discharges.

The new philosophy of legal controls provides for Federal involvement in ground water quality, as well as that of the contiguous zone and the oceans, in sedimentation and the prevention and abatement of pollution from agriculture and other non-point sources, in thermal pollution, in acid mine drainage, and with toxic substances. The Federal Government is mandated to develop and publish guidelines for effluent limitations identifying the best practicable control technology currently available for classes and categories of point sources, other than publicly owned treatment works, and guidelines for identifying and evaluating the nature and extent of non-point pollutants and processes, procedures, and methods to control pollution resulting from agricultural and silvicultural activities, mining activities, construction activities, disposal of pollutants in wells and changes that may be produced in ground waters. National standards of performance to control the discharge of pollutants are to be proposed and published as regulations for some 27 new sources of industrial waste water categories. Toxic pollutants are to be identified and a regulation is to be published with a proposed effluent standard or a prohibition for such pollutants or combinations thereof. A section on clean lakes provides for State identification and classification of lakes according to their eutrophic condition and permits Federal support in undertaking methods and procedures to restore the quality of such lakes. Federal criteria are to be developed and published for the discharge of materials into the territorial sea, the waters of the contiguous zone or the oceans. Permits may be issued for the discharge of dredged or fill material into the navigable waters at specified disposal sites providing criteria are met that were developed to define acceptable materials for disposal. The new legislation also would authorize very substantial increases in government funds to support construction of waste water treatment facilities and provides for loans to small business concerns to meet water pollution control requirements established under the Federal Water Pollution Control Act.

In the early history of water pollution control legislation, the concern of the Nation was centered on the control of oil pollution on the high seas and later on assisting the States with Federal monies for the planning of pollution abatement facilities and for the construction of waste water treatment plants. Municipal waste water treatment facilities received principal emphasis. More recently, national attention has focused on maintaining ambient water quality suitable to support the desirable and designated water uses for the Nation's waters. Attention has focused also on the industrial waste component of the total pollutional complex. A need has remained to focus attention on nonpoint source wastes arising from confined animal feeding areas, irrigation return flows, logging practices, construction site siltation, and rural sewage treatment devices. The need has existed also to focus on problems of eutrophication in specific lakes and to manage the wastes entering these drainage basins in such a manner that lake quality will be preserved for the uses of posterity. These needs are fulfilled in present legislative acts. The control philosophy is likewise changing to one of exerting maximal control of pollution at the source through the institution of effluent limitations rather than efforts to maintain a particular water quality without specific regard for each source of pollution that may affect the receiving water quality. We must now move forward as a society to translate the will of the people into a pollution control action program that will enhance environmental quality and insure its continued maximal usefulness.

5

Pollution Caused Environmental Changes

LIFE in water is influenced by water temperatures, dissolved oxygen, pH, color, turbidities, suspended and total dissolved solids, total alkalinity, nutrients, mineral composition, and a host of other physical, chemical, and biological entities.

Maximal values, and in some cases minimal values also, of these constituents often create an environment that becomes intolerable to particular organisms. This results in limiting productivity or interferes subtly with physiological processes that in turn reduce the organism's ability to compete with others within its environment throughout its life span.

The Varieties of Pollution

The effects of pollution upon the water environment assumes many characteristics, as well as an infinite variation in degree. The specific environmental and ecological responses to a given pollutant depend largely on its volume combined with the characteristic of the waste water, and the volume and characteristics of the receiving water into which it flows. Pollutants may provide an aesthetic insult, a toxic action, a blanketing effect that destroys the stream or lake bed, a biodegradable, organically-decomposable material that removes the dissolved oxygen from the water, a hazard to the health of man and other animals that use the water, a substance that magnifies in concentration as it becomes escalated through the aquatic food web, an alterant of water temperature which is the prime regulator of natural processes within the water environment, and a supplier of fertilizing nutrients that stimulate excessive production among some aquatic species.

Aesthetic Insults

The discarded object that results in an aesthetic environmental insult can be an asset as far as life in water is concerned. In some situations the discarded automobile tire or baby carriage may provide additional substrate area for some types of organisms to colonize, provided other aspects of the physical and chemical characteristics of the waterway support such biotic development. Many streams naturally lack appropriate substrates for the attachment of various macroorganisms that can supply food for a fishery in these areas. Artificial materials are often introduced in lakes as a management practice both to furnish a site for the development of fish food organisms and to act as a harbor of security for the fish population that is attracted to the device. In these cases, notably rare, the aesthetic liability of the discarded material must be weighed against its assets for the production of a higher-use waterway.

Many aesthetic insults on the aquatic environment do not possess possibilities for biotic improvement within the waterway. Colors that are introduced may decrease substantially the light penetration that is necessary for photosynthetic oxygen production and they tend to discourage sport fishing and interfere with the functioning of the gear used by the commercial fishermen. Increased turbidity through the introduction of clays has a similar detrimental effect and in addition the clays may carry nutrients or toxic substances as adsorbed materials. Bacterial slimes are a classic example of aesthetic insults and are a result of other direct and immediate pollutional conditions rather than a result of direct discharge of slime material, except as an unnecessary discharge from a waste water treatment operation.

Toxic Substances

Wastes containing concentrations of heavy metals or other toxic substances either individually or in combination may be toxic to aquatic organisms and thus have a severe impact on the water community. Fish kills are often the result of direct toxicity. Such acute toxicity may be so broadly effective that many life forms are damaged at one time, or it may be highly selective. Acute toxicity may result from a low concentration of a highly toxic material or a high concentration of a less toxic material. Often acute toxicity appears as a "slug" or a high concentration resulting from a dump or a stream of a toxic material. Such a concentration of material may be followed by normal, relatively non-toxic conditions, as the mass of water containing the poison flows downstream or is deflected by tidal movements.

Toxic actions that may require weeks or months to be noticed may be referred to as low-level, cumulative, or chronic toxicity and is most often observed as a reduction in the production of a particular type of organism. Slowly toxic materials may be more deleterious to a particular developmental stage rather than to the adult organism. Low level toxicities may change the entire population balance by a number of processes:

1. Susceptible species of either fish or fish food organisms may gradually die off thereby permitting tolerant species that are less desirable to man to flourish because of a lack of competition.
2. If algae or invertebrate food organisms are killed by a low-level toxicity, fish may die or move out of the area because of an inadequate food supply.
3. Weakened individuals surviving near the threshold of their tolerance are more susceptible to attack by parasites and disease such as the aquatic fungus, *Saprolegnia*.
4. Reproductive potential may be altered because eggs or very young individuals may be more susceptible to the low-level toxic substance than are the adults. The end result of such toxicity can be a slow and subtle alteration of the characteristics of the biological stream or lake inhabitants.

Sublethal concentrations of chemicals such as phenol, benzene oil, 2-4, D and others may impart an unpleasant flavor to fish flesh even when present in very dilute concentrations. This can be as detrimental to a fishery as a more direct fish kill because the waterway will not be used in the recreational pursuit for which it would otherwise be adapted. Shellfish are affected by organoleptic producing pollutants as are fin fish.

Fish may be repelled or driven out of an area by chemicals they find obnoxious. This may result in their scarcity or absence from a given locale or it may prevent their migrating to another area to spawn. In either case the species will soon disappear and be lost to the fishing community.

Silts and Settleable Solids

Deposition of inert precipitates and silts tend to smother bottom organisms. The general effect on the aquatic environment of inorganic silts is to reduce severely both the kinds of organisms present and their individual numbers. As particulate matter settles to the bottom it blankets the substrate and forms an undesirable, physical environment for organisms that would normally occupy such a habitat. Erosion silts alter aquatic environments chiefly by screening out light, changing heat radiation, blanketing the stream bottom, retaining organic materials, and carrying nutrients or toxic substances.

Developing eggs of fish and other organisms are smothered by deposits of silt. Fish food invertebrates are either destroyed or driven from the area because a stream bed that once was composed of rubble and filled with living spaces now has been paved with an innocuous substance that cannot be penetrated by the fragile creatures. Blanketing materials may be biodegradable organic substances and as such may have additional undesirable qualities in that oxygen is removed from the superimposed water during the decomposition of the sludge beds and, additionally, a food supply is afforded sludge-dwelling organisms, which multiply in great numbers.

The organic fraction of settleable solids includes greases, oils, tars, animal and vegetable fats, feedlot wastes, paper mill fibers, synthetic plastic fibers, sawdust, hair, greases, and various settleable materials from city sewers. In addition to depleting the dissolved oxygen, such materials produce hydrogen sulfide, carbon dioxide, methane or other noxious gases when undergoing decomposition.

The inorganic components of settleable solids include silts from construction activities and clays originating from such sources as erosion, placer mining, mine tailing wastes, strip mining, gravel washing, dusts from coal washeries, loose soils from freshly plowed farmlands, highway construction, and other building projects. Under poor farming practices, for example, as much as 11 tons of silt per acre per year may be washed by surface water into a drainage basin. Dredging of tidal rivers becomes a necessity for the continuation of navigation. The disposal of dredge spoils, often containing high concentrations of pollutional substances, becomes a matter of grave concern and a financial

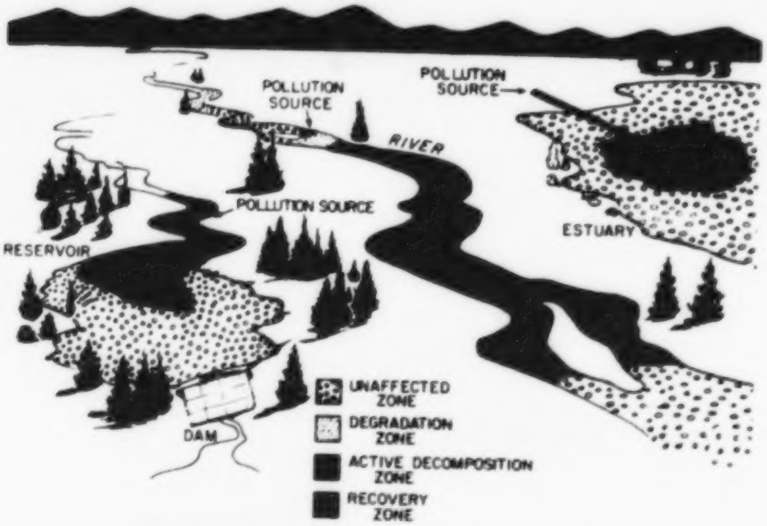

Plate 13. Benthic zones of pollution (organic wastes).

burden that could be prevented in large measure through universal adoption of control measures to prevent or reduce the amounts of silts and clays reaching the waterways.

Organic Wastes

Organic or biodegradable wastes are attacked by bacteria upon entering the water environment and during this process of decomposition the dissolved oxygen, so necessary for life within water, is used and reduced. When the organic load to the receiving waterway is heavy, all of the dissolved oxygen may be so used and the waterway becomes anaerobic and, from the standpoint of aquatic life, virtually dead. In addition to the oxygen-consuming properties associated with organic wastes, solids may settle to the waterway's bottom forming sludge banks that not only continue to exert an oxygen demand during the decomposition process but also furnish an ideal habitat for the development and reproduction of tremendous numbers of sludgeworms. Some types of organic wastes such as fibers from paper mills, for example, may form cohesive mats and with associated waste products, become lifted from the remaining sludge banks by the gases of decomposition. These "boils" of sludge can be transported downstream where they may settle in a new area and extend the zone of pollution. Organic wastes are often associated also with nutrients such as high concentrations of nitrogen and phosphorus. When the waterway has been cleansed of its visible signs of pollution through natural and biological actions, and the water clears, the nutrients often persist to stimulate obnoxious growths of plants or animals in downstream areas.

Upstream from the introduction of organic wastes, classic description details a clean-water zone or one that is not affected by pollutants. At the point of waste discharge, and for a short distance downstream, there is formed a zone of degradation where wastes become mixed with the receiving waters, and where the initial attack is made on the wastes by bacteria and other organisms in the process of decomposition.

Following the zone of degradation, there is the zone of active decomposition that may extend for miles, or days of stream flow, depending in large measure on the volume of dilution that is afforded the waste by the stream and the water temperature that affects the rate of biological decomposition. The biological processes that occur within this zone are similar in many respects to those that occur in a waste water treatment plant utilizing a biological process of waste treatment. Within this zone, waste products are decomposed and those products that are not settled as sludge are assimilated by organisms in life processes.

A zone of recovery follows the zone of active decomposition. The recovery zone is essentially a reach of water in which the quality is gradually returned to that which existed prior to the entrance of pollutants. Water quality recovery is accomplished through physical, chemical, and biological interactions within the aquatic environment. The zone of recovery may extend also for many miles and its extent will depend principally upon morphometric features of the waterway.

Finally, the zone of recovery terminates in another zone of clean water or an area unaffected by pollutants that is similar in physical, chemical, and biological features to that which existed upstream from the pollution source.

A general axiom of water pollution biology is that water pollution is associated with a reduction in the numbers of species of organisms that otherwise would be present in a particular aquatic situation. In field examination, this species reduction can be demonstrated by comparing samples taken from a polluted area with those samples taken from a similar aquatic habitat in an area not so affected. Depending upon the type of pollution, the reduction in species is associated also with either a tremendous increase or a reduction in the numbers of individuals representing a given species within the habitat. An increase in such numbers, such as sludgeworms or midges or even a species of algae, is indicative of an environment that restricts all but the most tolerant aquatic species and in addition furnishes a seemingly unlimited food supply for the growth and development of those species that are able to survive. A reduction in the number of individuals representing a given species would be indicative of conditions that

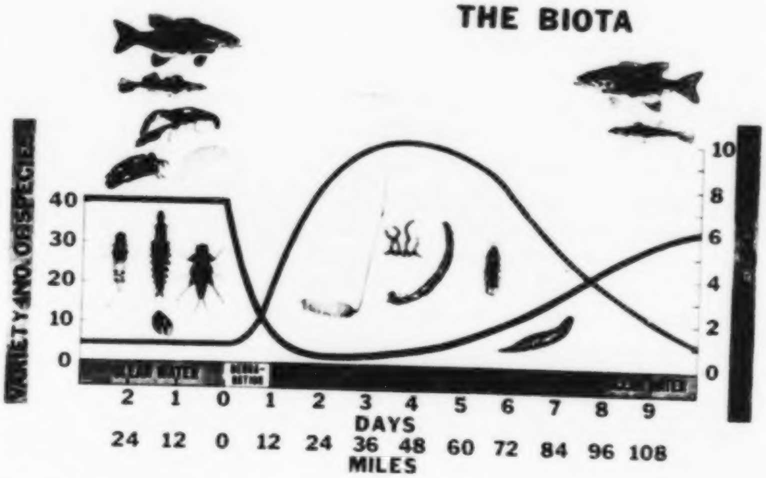

Plate 14. Response of organisms toward organic pollution in days of stream flow and miles of stream.

are toxic or restrictive to all but the most tolerant types of organisms. An additional food supply is not present.

Within the zone of active decomposition, conditions of existence for aquatic life are at their worst. The breakdown of organic products by bacteria may have consumed available dissolved oxygen. Sludge deposits may have covered the stream bed thus eliminating dwelling areas for the majority of bottom-associated organisms that could be found on a similarly unaffected area. Fish spawning areas have been eliminated but perhaps fish are no longer present because of the diminished oxygen supply and the substantially reduced available natural food. Here, aquatic plants will not be found in large numbers because they cannot survive on the soft, shifting blanket of sludge. Turbidity may be high and floating plants and animals destroyed. Water color may be substantially changed. When organic materials are decomposed, a seemingly inexhaustible food supply is liberated for those particular organisms that are adapted to use this food source. Thus bacteria and certain protozoan populations may increase to extremely high levels. Those bottom-associated organisms such as sludgeworms, bloodworms, and other worm-like animals may also increase to tremendous numbers because they are adapted to burrowing within the sludge, deriving their food therefrom, and existing on sources and amounts of oxygen that may be essentially nondetectable

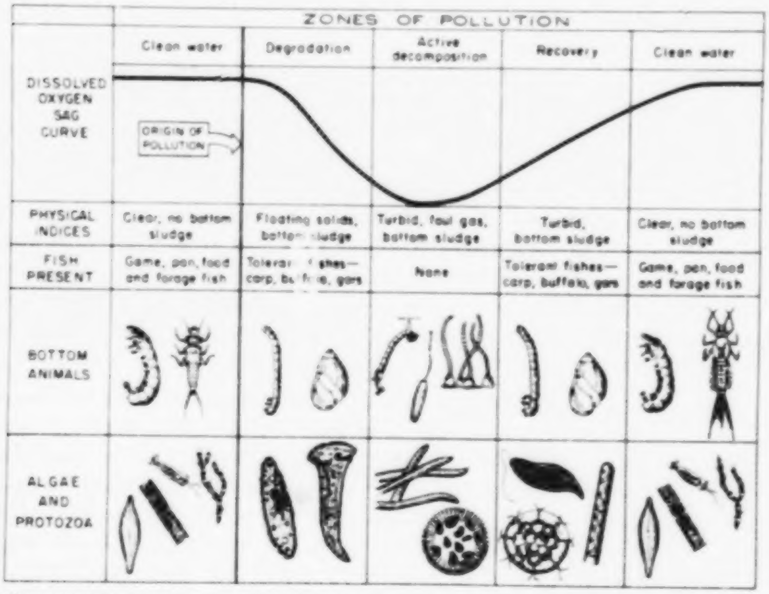
ZONES OF POLLUTION
Clean water
Degradation
Active decomposition
Recovery
Clean water
DISSOLVED OXYGEN SAG CURVE
ORIGIN OF POLLUTION
PHYSICAL INDICES
Clear, no bottom sludge
Floating solids, bottom sludge
Turbid, foul gas, bottom sludge
Turbid, bottom sludge
Clear, no bottom sludge
FISH PRESENT
Game, pan, food and forage fish
Tolerant fishes— carp, buffalo, gars
None
Tolerant fishes— carp, buffalo, gars
Game, pan, food and forage fish
BOTTOM ANIMALS
ALGAE AND PROTOZOA

Plate 15. Diagrammatic presentation of the zones of pollution showing types of bottom animals, algae, and physical indices associated with pollution.

by conventional field investigative methods. Within the zone of active decomposition the species that can tolerate the environment are few. Under some conditions, those bottom-associated animals that are visible to the unaided eye may be completely eliminated. Because of the tremendous quantity of food that is available to those organisms that are adapted to use it, the number of individuals of the surviving species may indeed be great. For example, it is possible to find in excess of 50,000 sludgeworms living within each square foot of bottom areas under conditions of severe organic pollution.

As organic wastes become more stabilized, other species of organisms predominate within the aquatic animal community. Midge larvae have been found to "paint" the stream bed with a brilliant red with their undulating bodies. Caddisfly larvae populations greater than 1,000 per square foot of stream bed or mayfly nymphs numbering more than 300 per square foot have been found on several occasions.

Organism's Effects on Pollution

The converse of the effects of pollution on organisms is the effects of organisms on pollutants. Organic wastes especially supply food which in turn produces an abundance of a few types of organisms greater than that produced in an unpolluted environment. In consuming such organic wastes, these organisms stabilize the waste material in a manner similar to that encountered in a biological sewage treatment plant. As stated above, the wet weight of sludgeworms in rich organic sludge may be as much as 25 tons per acre of sludge and they may move tremendous quantities of sludge per day by passing it through their digestive tract. If it were not for the action of such organisms on organic wastes, the extent of environmental damage from pollution would be tremendously expanded. For example, the purpose of a waste water treatment plant utilizing the biological process is to accomplish in an artificially confined area the same type of waste conversion that occurs in a natural stream. Such conversion is accommodated by supplying the right type of organism substrate for maximum efficiency and by aiding the process with mechanical devices and sometimes with the addition of air for an oxygen supply.

Biological magnification is an additional chronic effect of toxic pollutants such as heavy metals, pesticides, radionuclides, bacteria, and viruses. Many animals and especially shellfish such as oysters have the ability to remove from the environment and store in their tissues substances present at nontoxic levels in the surrounding water. This process may continue in the oyster or fish for example until the body burden of the toxin reaches such levels that the animal's death would result if the pollutants were released into the bloodstream by a physiological activity. This may occur as in the case of chlorinated hydrocarbon pesticides such as DDT and endrin, which are stored in fat deposits, when the animal's food supply is restricted and the body fat is utilized. The presence of the toxin that enters the blood stream causes the death of the animal. Equally disastrous is the mobilization of body fat to form sex products, which may contain sufficiently high levels of the pollutant so that normal development of the young is impossible.

Herbivorous and carnivorous fish at lower trophic stages may gradually build up DDT residues of 15 to 20 mg/l without apparent ill effect. Carnivorous fish, mammals, and birds preying on these contaminated fish may be killed immediately or suffer irreparable damage because of the pesticide residue or infectious agent.

Heat Pollution

Temperature, a catalyst, a depressant, an activator, a restricter, a stimulator, a controller, a killer, is one of the most important and influential water quality characteristics to life in water. Temperature determines those species that may be present; it activates the hatching of young, regulates their activity, and stimulates or suppresses their growth and development; it attracts, and kills when the water becomes too hot or becomes chilled too suddenly. Colder water generally suppresses development; warmer water generally accelerates activity and may be a primary cause of aquatic plant nuisances when other environmental factors are suitable.

Temperature is a prime regulator of natural processes within the water environment. It governs physiological functions in organisms and, acting directly or indirectly in combination with other water quality constituents, it affects aquatic life with each change. These effects include chemical reaction rates, enzymatic functions, molecular movements, and molecular exchanges between membranes within and between the physiological systems and the organs of an animal. Because of the complex interactions involved and often because of the lack of specific knowledge or facts, temperature effects as they pertain to an animal or plant are most efficiently assessed on the basis of the net influence on the organism.

Chemical reaction rates vary with temperature and generally increase as the temperature is increased. The solubility of gases in water varies with temperature. Dissolved oxygen is decreased by the decay or decomposition of dissolved organic substances; the decay rate increases as the temperature of the water increases reaching a maximum at about 30°C (86°F). The temperature of stream water, even during summer, is below the optimum for pollution-associated bacteria. Increasing the water temperature increases the bacterial multiplication rate when the environment is favorable and the food supply is abundant. Increasing the water temperature within the growth range of the bacteria causes a more rapid die-off when the food supply is limiting.

Warm water fish can survive temporarily in waters heated artificially to 33.9°C (93°F); some fish populations however such as those of roach, perch, and carp are reduced at these high temperatures. In cold weather, water temperatures must be substantially reduced at all points to prevent fish mortalities when fish move through changing temperature gradients. Cold water nonanadromous fish populations such as trout should not be subjected to temperatures exceeding 13.5°C (58°F). Sudden changes in temperature can be more harmful to some species of fish than continued exposure to a higher temperature. Fish can adapt to higher temperatures faster than to lower temperatures. The maximal temperature for a given species of fish varies with the fish's rate of heating, size, and physiological condition. Fish may starve at elevated temperatures because of their inability to capture food, which will be accentuated by a reduced swimming speed and the stress placed on physiological activities. Likewise, the toxic effects of potential toxicants to fish increase with temperature.

There are restricted ranges of temperature within which fish can reproduce successfully. Larval development especially requires very

Plate 16. Trash deposited on an area subject to flooding will pollute a receiving waterway with the next flood.

narrow ranges of temperature. A fish population may exist in a heated area only by continued immigration of individuals from the outside. Fish may be absent from such areas during warm summer months but be attracted to the warmer temperatures in cold winter months. Increased temperature may block the migration of anadromous fishes.

When water temperatures increase, the predominant algal species may change from diatoms to green algae and finally at high temperatures to blue-green algae because of species temperature preferentials. The number and distribution of benthic organisms decrease as water temperatures increase above 90°F, which is close to the tolerance limit for the population. Adult stages of many fish species are able to tolerate higher temperatures than eggs or young.

Certain benefits, including open-water winter fishing in otherwise ice covered areas and a cold water fishery downstream from deep reservoirs in an otherwise warm water region, can be derived from artificially induced temperature changes. The benefits of fish being attracted to heated water in winter months may be negligible compared to fish mortalities that may result when the fish return to the cooler water.

Nutrients

Eutrophication is a term meaning enrichment of waters by nutrients through either man-created or natural means. Present knowledge indicates that the fertilizing elements most responsible for lake eutrophication are phosphorus and nitrogen. Iron and certain "trace" elements are also important. Sewage and sewage effluents contain a generous amount of those nutrients necessary for algal development.

Lake eutrophication results in an increase in algal and weed nuisances and an increase in midge larvae, whose adult stage has plagued man in Clear Lake, California, Lake Winnebago, Wisconsin, and several lakes in Florida. Dense algal growths form surface water scums and contribute to algal-littered beaches. Water may become foul-smelling. Filter-clogging problems at municipal water installations can result from abundant suspended algae. When algal cells die, oxygen is used in decomposition, and fish kills have resulted. Rapid decomposition of dense algal scums, with associated organisms and debris, gives rise to odors and hydrogen sulfide gas that creates strong citizen disapproval; the gas often stains the white lead paint on residences adjacent to the shore.

Nitrogen and phosphorus are necessary components of an environment in which excessive aquatic growths arise. Algal growth is influenced by many varied factors: vitamins, trace metals, hormones, auxins, extracellular metabolites, autointoxicants, viruses and predation and grazing by aquatic animals. Several vitamins in small quantities are requisite to growth in certain species of algae. In a freshwater environment, algal requirements are met by vitamins supplied in soil runoff, lake and stream bed sediments, solutes in the water, and metabolites produced by actinomycetes, fungi, bacteria, and several algae.

Evidence indicates that: (1) High phosphorus concentrations are associated with accelerated eutrophication of waters, when other growth promoting factors are present; (2) aquatic plant problems develop in reservoirs or other standing waters at phosphorus values lower than those critical in flowing streams; (3) reservoirs and other standing waters collect phosphates from influent streams and store a portion of these within consolidated sediments; and (4) phosphorus concentrations critical to noxious plant growths vary, and they produce such growths in one geographical area, but not in another. Potential contributions of phosphorus to the aquatic environment have been indicated in the literature (Table 1). Phosphorus is temporarily stored in bottom sediments or transported as a portion of the stream's bed-load after its removal from the flowing water. Long-term storage is effected when the phosphorus is pooled in deltas or deposited on flood plains.

Table 1. Pounds of Phosphorus Contributed to Aquatic Ecosystems

Major Contributors:
  Sewage and Sewage Effluents: 3 lbs. per capita per year.*
  Some industries, e.g., potato processing: 1.7 lb. per ton processed.
  Phosphate rock from 23 states (Mackenthun and Ingram, 1967).
  Culivated agricultural drainage: 0.35-0.39 lb. per acre drained per year Engelbrecht and Morgan, 1961) (Sawyer, 1947) (Weibel, 1965).
  Surface irrigation returns, Yakima River Basin: 0.9-3.9 lbs. per acre per year (Sylvester, 1961).
  Benthic Sediment Releases.

Minor Contributors:
  Domestic duck: 0.9 lb. per year (Sanderson, 1953).
  Sawdust: 0.9 lb. per ton (Donahue, 1961).
  Rainwater.**
  Groundwater, Wis.: 1 lb. per 9 million gals. (Juday and Birge, 1931).
  Wild duck: 0.45 lb. per year (Paloumpis and Starrett, 1960).
  Tree leaves: 1.8-3.3 lb. per acre of trees per year (Chandler, 1943).
  Dead Organisms; animal excretions.

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* Various researchers have recorded the annual per capita contribution of phosphorus in pounds from domestic sewage as 2 to 4 (Bush & Mulford, 1954), 2, 3 (Metzler et al., 1958), 1.9 (Owen, 1953), and 3.5 (Sawyer, 1965).

** Influenced by pollution present in atmosphere "washed out" by rainfall.

Once nutrients are combined within the ecosystem of the receiving waters, their removal is tedious and expensive; removal must be compared to inflowing quantities to evaluate accomplishment. In a lake, reservoir, or pond, phosphorus is removed naturally only by outflow, by insects that hatch and fly out of the drainage basin, by harvesting a crop, such as fish, and by combination with consolidated bottom sediments. Even should adequate harvesting methods be available, the expected standing crop of algae per acre exceeds 2 tons and contains only about 1.5 lbs of phosphorus. Similarly, submersed aquatic plants could approach at least 7 tons/acre (wet weight) and contain 3.2 lbs/acre of phosphorus. Probably only half of the standing crop of submersed aquatic plants can be considered harvestable. The harvestable fish population (500 lbs.) from 3 acres of water would contain only 1 lb. of phosphorus.

Dredging has often been suggested as a means of removing the storehouse of nutrients contained within the lake bed sediments. These sediments are usually rich in nitrogen and phosphorus, for they represent the accumulation of years of settled organic materials. Some of these nutrients may be recirculated within the water mass and furnish food for a new crop of organic growth. However, in an undisturbed mud-water system, the percentage of nutrients, as well as the amount of phosphorus that is released to the superimposed water, is very small.

Oil

The effects of oil substances on aquatic life in freshwater may be summarized as follows:

(1) Free oil and emulsions may coat and destroy algae and other plankton;

(2) heavy coatings of free oil on the surface may interfere with the natural processes of reaeration and photosynthesis, while light coatings would be less detrimental because wave action and other turbulence would maintain adequate reaeration; and

(3) water soluble principles may exert a direct toxic action.

The deleterious effect of crude oil and lubricating oils on fish is due to a film formed over the gill filaments of fish, which prevents the exchange of gases and results in suffocation.

The effects of oils on marine animals may include the tainting of fish and shellfish flesh, poisoning by ingestion of oil or soluble fractions, such as phenol, ammonia, and sulfides, disturbances of marine food webs, and physical fouling of animals with heavy coats of oil.

Many thousands of waterfowl have been destroyed by the effects of oil pollution. This wasteful loss has deprived nature lovers, waterfowl hunters, and bird watchers of immeasurable enjoyment. The destruction of many duck species, such as the canvas back, redhead, and scaups, comes at a critical period for these species that are fighting for survival against the forces of nature. In future years additional waterfowl will be destroyed if oil dumping is continued, especially in late winter. In this modern age of technical development, the discharge of oil into a river system indicates man's lack of responsibility for the preservation of our natural resources.

The effects of oil on birds depend upon a variety of factors including the type of oil, extent of contamination of plumage, temperature of the air and water, and the quantity of oil ingested. Migratory birds may be affected indirectly by deposits of oil on the bottom, in shallow water, or along the shore that reduce the available food supply by destroying both plants and animals. Elements within the food chain are eliminated by chemical or physical properties of the oils and food for waterfowl may become unavailable by being coated or embedded in the oily materials. Accumulation of petroleum sludge may also prevent germination and growth of plants and the production of invertebrates important as food, either by smothering or through toxic effects.

Oil causes matting of the ducks' feathers so that ducks become water-logged, lose their ability to fly and drown if they cannot get out of the water soon enough. It breaks down the insulating power of the feathers; body heat and stored energy reserves are lost rapidly. Diving ducks may starve and, following the preening of oil from contaminated feathers, bleeding ulcers may be produced in the digestive tract causing mortality.

6

Helpful References

THERE are many references helpful to the investigators of water quality problems and to the interpretation of data that are collected in investigations. This chapter contains a selected listing of some of the more useful books that have been compiled to respond to the needs in this field of endeavor. All or most of these books should be available in a local library, but some of them should be purchased and retained for day-to-day reference by the investigator who must interpret and strive to correct water quality problems on a recurring basis. Some of the references are of such significance to the determination of water quality, to the particular water quality requirements for specific uses, and to the interpretation of data obtained from field investigations that they warrant special discussion.

A very comprehensive, useful, and authentic publication is that of "Standard Methods for the Examination of Water and Wastewater" currently in its 13th edition, copyrighted 1971 by the American Public Health Association, 1015 18th Street, N.W., Washington, D. C. 20036. "Standard Methods" was first published in 1905. Its goal has been to represent the best current practices of American water analysts, and to be generally applicable in connection with the ordinary problems of water purification, sewage disposal, and sanitary investigations. The book is currently revised on a five-year schedule. The present edition contains 874 pages that are devoted to chemical, microbiological, and biological methods that have withstood the innumerable tests of time and the scrutiny of analytical peers before being recognized as standard procedures. The last approximately 100 pages of the volume are devoted to biological methods for waterway investigations, which were revised particularly for the 13th edition. The book contains a key to major groups of aquatic organisms, a host of helpful plates for gross identification of plants and animals, a key for the identification of fresh-water algae, and a reproduction in color of six plates of algae grouped according to habitat preference. "Standard Methods" is an extremely helpful document both to the experienced investigator who must ensure himself that the methods of his investigation will withstand the scrutiny of the scientific community, and also to the novice investigator who will find the biological and other discussions on methods of investigation, as well as keys in identifying animals and plants, helpful in pursuing his investigations.

The definition of a water quality amenable for defined water uses had its genesis in a 1952 publication by the State of California, in a book entitled "Water Quality Criteria." This effort was expanded and tremendously enhanced in a 2nd edition edited by Messrs. Jack E. McKee and Harold W. Wolf and published in 1963 by the Resources Agency of California, State Water Quality Control Board, Sacramento, California. This edition, including 3,827 cited references, was a monumental effort in bringing together under one cover the world's literature on water quality criteria as of the date of publication. Criteria were identified and referenced for a host of water quality characteristics according to their effects on domestic water supply, industrial water supplies, irrigation waters, fish and other aquatic life, shellfish culture, and swimming and other recreational uses. Specific values were arranged in ascending order, with appropriate references, as they had been reported as lethal or damaging to fish or as not harmful to fish in the indicated time and under the conditions of exposure. The results of such a tabulation presented a range of values and, as would be expected by those investigating such conditions, there was often an overlap in values between those concentrations that have been reported by some investigators as harmful and those concentrations that have been reported by other investigators as not harmful. Such an anomaly is due to differences in investigative techniques among investigators, the characteristics of the water used as a diluent for the toxicant, the physiological state of the test organisms, and variations in the temperature under which the tests were conducted. Nevertheless, the tabulation of criteria values for each of the water quality constituents has been helpful through time to predict a range within which a water quality constituent would have a deleterious effect upon the receiving waterway. The State of California "Water Quality Criteria" publication is currently being enlarged and updated through a series of publications developed through contracts with consultants by the Environmental Protection Agency. These publications appear as volumes of a "Water Quality Criteria Data" book. Volume I is subtitled "Organic Chemical Pollution of Freshwater." Volume II is subtitled "Inorganic Chemical Pollution of Freshwater." The third is subtitled "Effects of Chemicals on Aquatic Life," and volume IV is "Recreational Water Quality Criteria." These volumes appear as a Water Pollution Control Research Series for the Environmental Protection Agency and are attainable from the Superintendent of Documents, Washington, D. C. Each volume contains a series of tables, one of which lists the concentrations of particular pollutants that have been found in water based on a search of the literature. Another table presents the pollutants' acute toxicological information for mammals. Another lists the mammalian and chronic toxicity of potential pollutants of water. Another table presents the concentration and effects of various pollutants in human and animal tissues and additional tables depict the carcinogenicity, mutagenicity, and teratogenicity of identified pollutants.

On April 1, 1968, the then Federal Water Pollution Control Administration published a book entitled "Water Quality Criteria." This book, obtainable from the Superintendent of Documents, Washington, D. C., was a report of the National Technical Advisory Committee to the Secretary of the Interior that constituted the most comprehensive documentation to date on water quality requirements for particular and defined water uses. The book was intended to be used as a basic reference by persons in State water pollution control agencies engaged in water quality studies and water quality standards setting activities. Recommendations and water quality constituent criteria designed to ensure a quality of water amenable to designated uses were recorded for recreation and aesthetics, public water supplies, fish and other aquatic life and wildlife, agricultural, and industrial uses. In some respects, this volume represented a marriage between the best available experimental criteria recorded in the literature and the judgment of recognized water quality experts with long experience in associated management problems.

The Environmental Protection Agency has contracted with the National Academy of Sciences and the National Academy of Engineering to revise and bring up to date the information contained in the 1968 Water Quality Criteria volume. Committees of experts have been laboring over the past year to complete this assignment. Final drafts of the 1972 version of "Water Quality Criteria" have been assembled. Publication is anticipated late in 1973. The revised volume represents an accumulation of the latest data and scientific judgments on this important and timely subject and, without question, will be a basic reference in connection with the interpretation of investigative water quality data for many years to come.

A selected alphabetical listing of additional references that should be helpful to the investigator follows:

AMOS, W. H. 1967. The Life of the Pond. McGraw-Hill, New York.

BARDACH, J. 1966. Downstream: A Natural History of the River From Its Source to the Sea. Grossett and Dunlap, New York.

BERNER, L. 1950. The Mayflies of Florida. University of Florida Press, Gainesville, Florida.

BURKS, B. D. 1953. The Mayflies, or Ephemeroptera, of Illinois. Bull. Illinois Nat. Hist. Surv.

CHU, H. F. 1949. How to Know the Immature Insects. Wm. C. Brown Co., Dubuque, Iowa.

Edmondson, W. T. 1959. Ward and Whipple's Fresh Water Biology (2nd ed.). John Wiley and Sons, New York.

Fassett, N. C. 1960. A Manual of Aquatic Plants (with Revision Appendix by E. C. Ogden). University of Wisconsin Press, Madison.

Frey, D. G. 1963. Limnology in North America. University of Wisconsin Press, Madison.

Frison, T. H. 1935. The Stoneflies, or Plecoptera, of Illinois. Bull. Illinois Nat. Hist. Survey.

Harvey, H. W. 1955. The Chemistry and Fertility of Sea Waters. Cambridge University Press, American Branch, 32 East 57th Street, New York.

Hawkes, H. A. 1963. The Ecology of Waste Water Treatment. Pergamon Press, New York.

Hutchinson, G. E. 1957. A Treatise on Limnology. John Wiley and Sons, Inc., New York.

Hutchinson, G. E. 1967. A Treatise on Limnology. Vol. 2: Introduction to Lake Biology and the Limnoplankton. John Wiley and Sons, Inc., New York.

Hynes, H. B. N. 1960. The Biology of Polluted Waters. Liverpool University Press, Liverpool.

Ingram, W. M., K. M. Mackenthun and A. F. Bartsch. 1966. Biological Field Investigative Data for Water Pollution Surveys. U. S. Department of the Interior, Federal Water Pollution Control Administration.

Jackson, D. F. Ed. 1964. Algae and Man. Plenum Press, New York.

Jackson, D. F., Ed. 1968. Algae, Man, and the Environment. Syracuse University Press, New York.

Jones, J. R. E. 1964. Fish and River Pollution. Butterworth, Inc., Washington, D. C.

Kittrell, F. W. 1969. A Practical Guide to Water Quality Studies of Streams. U. S. Department of the Interior, Federal Water Pollution Control Administration.

Klein, L. 1959. River Pollution 1. Chemical Analysis. Butterworths, London.

Klein, L. 1962. River Pollution 2. Causes and Effects. Butterworths, London.

Klein, L. 1966. River Pollution 3. Control. Butterworths, London.

Klots, E. B. 1966. New Field Book of Freshwater Life. G. P. Putnam's Sons, New York.

Macan, T. T. 1963. Fresh-Water Ecology. John Wiley and Sons, Inc., New York.

Macan, T. T. and E. B. Worthington. 1951. Life in Lakes and Rivers. The New Naturalist. Collins, London.

Mackenthun, K. M. 1969. The Practice of Water Pollution Biology. U. S. Department of the Interior, Federal Water Pollution Control Administration.

Morgan, A. H. 1930. Fieldbook of Ponds and Streams. G. P. Putnam's Sons, New York.

Muenscher, W. C. 1944. Aquatic Plants of the United States. Comstock Publishing Co., Ithaca, New York.

Needham, J. G. and P. R. Needham. 1962. A Guide to the Study of Fresh-Water Biology (5th Ed.). Holden-Day, Inc., San Francisco, California.

Pennak, R. W. 1953. Fresh-Water Invertebrates of the United States. The Ronald Press Co., New York.

Pratt, H. S. 1951. A Manual of the Common Invertebrate Animals Exclusive of Insects. The Blakiston Co., Philadelphia.

Prescott, G. W. 1962. Algae of the Western Great Lakes Area (rev. ed.). Wm. C. Brown Co., Dubuque, Iowa.

Reid, G. K. 1967. Pond Life: A Guide to Common Plants and Animals of North American Ponds and Lakes. Golden Press, New York.

Ross, H. H. 1944. The Caddis Flies, or Trichoptera, of Illinois. Bull. Illinois Nat. Hist. Survey.

Ruttner, F. 1963. Fundamentals of Limnology (3rd ed.). University of Toronto Press, Toronto, Canada.

Smith, G. M. 1950. The Fresh-Water Algae of the United States. McGraw-Hill, New York.

Tiffany, L. H. and M. E. Britton. 1952. The Algae of Illinois. The University of Chicago Press, Chicago, Illinois.

Tryon, C. A. and R. T. Hartman. 1960. Ecology of Algae. Pymatuning Laboratory of Field Biology. University of Pittsburgh, Pennsylvania.

Usinger, R. L. 1956. Aquatic Insects of California With Keys to North American Genera and California Species. University of California Press, Berkeley.

Welch, P. S. 1948. Limnological Methods. Blakiston Co., Philadelphia.

Welch, P. S. 1952. Limnology. McGraw-Hill, New York.

Whipple, G. C. (Rev. by G. M. Fair and M. C. Whipple). 1948. The Microscopy of Drinking Water (4th ed.). John Wiley and Sons, New York.

7

Investigative Preparation and Techniques

Objectives

STUDY objectives are a necessary and important beginning to any investigation. Careful thought and consideration should be given to their development. The objective should encompass clear, concise, positive definitions of the investigation's purpose, its scope, and its boundary limits. Study objectives should be realistically oriented to the number, competencies, and disciplines of the investigators. They should be adjusted to budgetary limitations for the study, as well as to the length of time allocated for the study, including the final report preparation. Ultimately, as the study progresses, and at its conclusion, the study's success and accomplishments will be judged in part on the extent to which it fulfilled the objectives stated at the study's instigation. Study objectives become important tools to guide subsequent investigations and to delineate avenues of approach toward problem solving.

Study objectives should be committed to writing as the first act in formulating an essential study plan. When properly developed, they will ensure adherence to essential investigation and discourage pursuit of the interesting but nonessential bypaths or tangential considerations that so often dominate and defeat a well intended purpose. Written objectives fix the responsibility of those charged with supervision of the study and they provide a basis for judging the extent to which the results meet the needs that justified the initial undertaking.

Waterways are studied for many reasons. One very excellent reason in the high school or beginning college curriculum is that of training the future investigators of this Nation in the science and art of using the tools of investigation successfully to formulate a sound judgment that accurately depicts existing conditions.

Studies of waterways may be designed to consider water quality at a single point or to determine changing water quality throughout a reach of waterway. The former involves one or more unrelated sampling stations on a water system whereas the latter involves an examination of data from a series of related sampling stations selected to reflect both instantaneous changes in water quality caused by waste discharges or major tributaries, as well as the more subtle changes that result from natural purification processes. In either case, samples may be collected from chosen stations on a periodic basis with the periodicity of sampling being determined by the types of samples being collected and the general needs of the study.

Objectives of water quality studies that require samples from a single station or isolated stations would include:

- The establishment of a baseline record of water quality.
- Investigation of the suitability of an area for a water supply source for municipal, industrial, agricultural, recreational, or other uses.
- Investigation of the suitability of water quality for the propagation of aquatic life, including fish.
- Monitoring waste water discharges and their effects at a particular site.
- Research or demonstration on analytical procedures for water quality examination.

Objectives that require the examination of water quality from stations located at related points on the waterway include:

- Determination of the nature and extent of pollution from point or non-point pollution sources.
- Determination of adherence to or violation of water quality standards.
- Determination of characteristics and rates of natural purification of waterways.
- Determination of causes of fish kills and other catastrophic events involving water quality deterioration.
- Determination of existing water quality through a waterway reach prior to some anticipated event that would be expected to alter water quality.
- Research and demonstration of techniques of waterway investigation.
- Serve as an environmental training laboratory to train water quality investigators.

- Serve as a basis for predicting water quality changes that may be caused by anticipated increased pollutional loads or the implementation of certain pollution abatement or control activities.
- Serve as a data base for projecting a cost-benefit analyses of a water management effort.

Planning

Planning for a waterway investigation involves a myraid of details that are essential for the completion of a successful study. The first essential activity is to become familiar with available information on the waterway under investigation that may relate to the present activity. Seldom is the investigation of a waterway an original event. Most lakes and streams in the Nation have been investigated to some extent by someone and many prognostications and predictions have been recorded by previous investigators relating to the quality of water within a given reach of the waterway or the effects of significant anticipated changes in the watercourse that may affect water quality. The results of these investigations and prognostications have been recorded in either published or unpublished reports, the latter of which may reside in a now obscure file of an appropriate State agency. Much time and effort in redoing what already has been done can be saved on the part of the investigator by searching out and becoming familiar with the past studies that relate to the waterway in question.

Good field maps of the watercourse under investigation must be secured and the points of access noted. Factors affecting the investigation should be recorded on the map and these include locations of various water uses, geographical boundaries such as State limits or other significant landmarks, and marked changes in waterway characteristics such as the entry of free-flowing streams into reservoirs or lakes. The approximate location of known waste sources such as industries, municipalities or other significant contributors should be marked. The approximate length of the waterway to be investigated should be noted, as well as the area of the watercourse that will impact the study. Tentative sampling stations should be selected from the maps based on points of access and stream mile designations developed for major landmarks on the waterway and the location of waste sources. Development of these conditions necessitates that the selected maps be accurate and of suitable scale.

Following a "desk top" analyses of available background data and a perusal of information gathered on the waterway by other previous investigators, a reconnaissance survey should be undertaken whenever time permits. During a reconnaissance survey a judgment can be reached on the potential effects on water quality of individual and combined waste sources, the reach or reaches of waterway that are of potentially greatest concern in the particular investigation, and points of access and anticipated sampling sites. Certain judgments should be reached during the reconnaissance survey that will save much time and effort at a later date. These would include the advantages and disadvantages of sampling by boat as opposed to collecting samples from bridges and by wading, or by a car top or trailered boat that may be lowered into the water from several points of access along the waterway. Reaching this decision will necessitate observations on stream width, depth, nature and type of stream bed, relative flow, as well as any morphometric features that would influence a sampling procedure. The availability of boats for rental along the waterway and the availability of suitable access points for the types of samples to be collected should be ascertained during such a reconnaissance. Also contacts may be made with local officials or local investigators who may be encouraged to participate in some manner with the actual investigation. Arrangement should be made with landowners to cross private lands at times when samples are to be collected from the waterway should this be a necessity.

A minimal number of samples should be collected from readily available access points along the waterway during the reconnaissance survey to ascertain the relative water quality at various points and to aid in the judgment of selecting sampling stations. This may involve the collection of water samples or certain chemical analyses and it should involve the examination of rocks, twigs, or submersed debris to ascertain the types of biota that are able to exist in a given reach of the waterway. Much can be determined about the water quality through a cursory examination of the types of attached organisms that may be found in a given area excluding the bacteriological water quality. Observations of visible conditions along a waterway associated with a brief examination of attached organisms on submersed objects should be sufficient to delineate appropriate sampling sites for future investigation.

Following the completion of a reconnaissance survey, and subject to modification or change during the course of the actual field sampling, decisions can be made on: (1) types of samples necessary to meet the objectives of the study (i.e., various physical, chemical, and, biological samples); (2) sampling points for each of the selected types of samples; (3) periodicity of sampling and approximate time necessary for collection of a specific sample; and (4) approximate numbers of samples necessary to meet the objectives of the study.

Often the objectives of the study will be sufficiently broad that a number of investigative disciplines will be required to complete the investigation. It is axiomatic that the chemist, microbiologist, water quality engineer, biologist, hydrologist, and others are equally essential to the development of a sound perspective of water quality.

The next aspect of study planning involves the details necessary to initiate the process of data collection. Decisions must be made on methods of sample handling between the point of collection and the point of analytical result, sample preservation, and transportation of samples to a base laboratory. Often biological samples may be preserved for examination at some future and more convenient time. Certain samples for chemical analyses also may be preserved for a short period of time until they can be analyzed at an appropriate laboratory where precision instruments are available. Sample collection containers must be obtained and the number of these will depend upon the relative number of samples to be collected during the investigation. Sampling equipment, data cards, notebooks, and all of the necessary paraphernalia associated with the collection, retention, and shipment of samples must be obtained and organized. Arrangements must be made to transport such equipment to the study site and to ensure that it is at hand when the field investigators arrive. Collecting and field analytical gear should be checked and rechecked to determine that no essential piece of equipment has been omitted from the materials necessary for the investigation and to determine that the equipment is operable and functions according to designed specifications. The planning of a local study as a part of a high school or college curriculum should be equally comprehensive not only because of its training value but also because the results of an investigation are influenced to a great extent by the preliminary planning that goes into the initiation of the investigation. Planning should be associated closely with the objectives that define the study.

If the study is some distance from the base of operations, a portion of the study planning involves the making of travel arrangements, room accommodations, transportation of samples and equipment to and from the sampling areas and arrangements for such items as transportation during the investigation, procurement of outboard motor gasoline, cartons or boxes for shipping collected samples, ice to keep certain samples cold if this is a prerequisite for analyses, and other considerations. Laboratories that will analyze collected samples should be alerted and given an estimate of the number and kinds of samples that will be submitted, the types of analyses required, how the samples will be shipped and the approximate dates of arrival. The laboratory should also be advised of the date their analytical results will be required to meet the investigation's deadline.

A preliminary cost estimate can now be made of the investigation under consideration and it may be that the first compromise of the ideal plan will be necessary. The cost must be adjusted to the available budget. The compromise may be in a reduction in the number of sampling stations, in the types of analyses to be made, in the number of samples to be obtained from each station, or in combination of these factors. Realistically, the conceived ideal for a field investigation is seldom achieved because of resource limitation or an alteration in time schedule that must be imposed upon the study at some point in its persual.

There are a number of sources of information concerning investigations or problems connected with water quality in waterways. One of the best sources is the State water pollution control agency. As would be expected, this agency usually has the most complete collection of information and data on factors involved with water quality within a State. They have conducted surveys over a number of years and have received complaints and statements from citizens over a long period of time concerned with this subject. Other State agencies that may have important data include the State Health Department, which is generally responsible for supervising public water supplies; the State Fish and Game Department; the State Geological Survey, which cooperates with the U. S. Geological Survey in the stream gaging program; and the Public Service Commission, which usually has jurisdiction over dams and obstruction to navigation. In addition, interstate agencies such as the Interstate Commission on the Potomac River Basin, the Delaware River Basin Commission, and the Ohio River Valley Water Sanitation Commission usually have information similar to that in State Water Pollution Control Agency files. Here the information may be confined to a river system rather than confined to a particular State boundary. The Environmental Protection Agency with its ten regional offices located in strategic cities throughout the United States has a great deal of particular information on the waterways of the Nation. The regional office in question should be contacted for water quality information as it may pertain to a particular study. Federal river development agencies, such as the U. S. Corps of Engineers, the Bureau of Reclamation of the U. S. Department of the Interior, and the Tennessee Valley Authority are all fertile sources of information on streams for which they have responsibility. The U. S. Geological Survey operates stream gaging stations and reports daily stream discharges throughout the Nation, usually in cooperation with the States. The U. S. Bureau of Sport Fisheries and Wildlife and the U. S. Marine Fisheries Service collect data on fish and fishing. Municipal water treatment plant operators have comprehensive records on the quality of the water serving their souce of raw water. Often these data include both chemical and biological constituents and the record of time for which these data have been collected extends through many years. Waste water treatment plant operators often keep a log of the quality of their waste water and, in rare instances, have data on stream water quality both upstream and downstream from their discharge point. Often particular individuals have had an interest in a particular statistic of water quality at a given point for a long period of time. These data may be very accurate but also may be difficult to authenticate. But, such data are a source of valuable information as background upon which to base further investigations.

Data Collection

The collection of data on a particular study involves talking to people who are concerned with the problem in question and in obtaining their views. Many of these citizens have had long experience with the problems and may be dissatisfied with the speed of obtaining visible water quality improvement. The views of laymen may indicate approaches that should be pursued in the investigation that otherwise might be omitted.

The collection of field data for a survey by a high school or college team need not be sophisticated. Visual observations of water quality conditions and abundant substantiating pictures of such observations are important components to depict the story of waterway conditions. A determination of the kinds of organisms attached to submersed objects within the waterway is an important adjunct to a study of this type. This determination can be made by use of such common tools as a garden rake or a dip net to obtain the sample or by picking up the submersed object by hand and washing or scrapping the attached organisms from it. The organisms are then identified to major groups and the numbers present in such groups should indicate in a very general way the water quality of the area from which the samples were obtained. Routine chemical samples can be analyzed by kits for such analyses, which contain the necessary fixative and testing chemicals. Field analytical kits have been found not to offer the precision that can be obtained with stationary equipment in a laboratory but they are entirely adequate for the type of study described above.

The collection of data and samples from a particular station involves making a number of scientific observations. Flow measurements on streams, inlets and outlets to standing bodies of water such as lakes and reservoirs, suspected municipal and industrial waste sources, and water use drawoff and return points, which can be correlated with sampling dates, are of utmost importance. Such data permit a calculation of the amounts of particular water quality constituents passing a point at a given time, and estimates can be made from these data on daily, monthly, or annual contributions. Rainfall may be a contributing factor to investigations concerning major aquatic plant nutrients and should be sampled to determine annual contributing amounts of

FIELD COLLECTION CARD

Date ________ Hour ______ Collector __________
Field Designation ______________________
Station Location ______________________
Sample No. ____________ Stream Miles ________
Weather ______________________
Bottom: ____ Rock: ____ C. Gravel F. ____: C. Sand F. ____
% : ____ Sandy Loam: ____ Silt Loam: ____ Silt:
: ____ C. Clay F. ____ : ____ Organic Sludge:
Sample Location ____________ Sample Depth ________
River: Width ________ Depth ________ Current ________
: Temp ________ DO ________ pH ________
: Phth Alk ________ Tot Alk ________ Cond ________
Sampler : Ek : Pet : Sq Ft : Qual : :
No. of Samples: : : : :
Fish: Gear : Shocker : Dip Net : Seine : :
Sample Time : : : : :
Sample Area : : : : :
Remarks:

Figure 1 Field Collection Card for Benthic Samples

Desired items for a field biological collection card may be arranged on a 5" x 8" unlined card for convenience. Cards can be carried in a field notebook; they may be filed after field and laboratory use. The backside of the card may be ruled to itemize the organisms observed in the laboratory examination of the collected sample.

nitrogen and phosphorus. A house-to-house survey of the area draining to a watercourse may be indicated to determine types of waste treatment and to project potential impact of wastes that are discharged to or reach the watercourse. The types and amounts of fertilizers applied to lands within the drainage basin, as well as the period of the year when fertilizers are applied, may be of importance to the study. Groundwater may be a factor and should be sampled from appropriate adjacent wells for those constituents of importance.

On approaching a stream station a number of observations must be made. Observations are made on water depth; presence of riffles and pools; stream width; flow characteristics; bank cover; presence of slime growths, attached algae, scum algae and other aquatic plants, as well as red sludgeworm masses; and unusual physical characteristics such as silt deposits, organic sludge deposits, iron precipitates, or various waste materials from manufacturing processes.

Organisms associated with the stream bed are studied most often in the biological evaluation of water quality. These organisms are valuable to relate water quality because they are not equipped to move great distances through their own efforts and, thus, remain at fixed points to indicate water quality. Because the life history of many of these organisms extends through one year or longer, their presence or absence is indicative of water quality within the past, as well as the present. Bottom-associated organisms are relatively easy to capture with conventional sampling equipment and the amount of time and effort devoted to their capture and interpretation is not as great as that required for other segments of the aquatic community.

The investigator should ask himself three basic questions: Based on a knowledge of preferred organism habitats, what bottom fauna should be expected at this station? Specifically, where would one expect to find these creatures? What is the appropriate gear with which to capture them? A close search of the respective areas should be made by noting and collecting qualitatively the various types of organisms. A commercial 30-mesh sieve is a handy exploratory tool.

The qualitative search for benthos should involve the collection of organisms from rocks, plants, submersed twigs or debris, or leaves of overhanging trees that become submersed and waterlogged. It is often convenient to scrape and wash organisms from these materials into a bucket or tub partially filled with water and then to pass this water through the sieve to concentrate and retain the organisms. The collected sample may be preserved for organism sorting and identification later. The investigator should search until he is certain that he has collected the majority of species that can tolerate the particular environment. In some environments it is possible only to collect qualitative samples because the physical nature of the waterway may be such that quantitative sampling is not feasible.

Qualitative sampling determines the variety of species occupying a reach of a waterway. Samples may be taken by any method that will capture representatives of the species present. Collections from such samplings indicate changes in the environment, but they generally do not accurately reflect the degree of change. Mayflies, for example, may be reduced in the stream because of adverse conditions from 100 to 1 per square foot, whereas sludgeworms may increase from 1 to 14,000 per square foot. Qualitative data would indicate the presence of both species, but might not necessarily delineate the change in predominance from mayflies to sludgeworms.

The basic principle in qualitative sampling is to collect as many different kinds of animals as practical. Obviously, because of the rarity of some forms, the probability of collecting a specimen of every kind is remote and a limit must be imposed on the collector's efforts. Two convenient limiting methods are:

(1) Presetting a time limit on the collector's effort at each sampling point. A minimum of 30 minutes and a maximum of an hour is a convenient range in which to establish this limit.

(2) Sampling in an area until new forms are encountered so infrequently that "the law of diminishing returns" dictates abandoning the sampling point. This method requires professional judgment—but if after 10 minutes only a single species or organism is found, the sampler can move to the next sampling site where he might continue to find new forms after searching more than an hour.

A number of tools readily obtained in any community are valuable in this type of sampling:

a. Pocket-knives are excellent tools to remove animals from crevices in rocks, to peel bark from decaying logs thus exposing animals, and to slip under animals to lift and transfer them to sample containers.

b. Mason jars in ½ to 1 pint sizes serve as the most economical sample containers and provide visibility of the preserved specimens.

c. Common garden rakes are valuable to retrieve rocks, brush, logs and aquatic vegetation for inspection.

d. Fine-meshed dip-nets are good devices for sweeping animals from vegetation or out from under overhanging rock ledges.

e. Buckets are handy to quickly receive rocks and debris, thus preventing escape of the swift running animals.

f. Sheet polyethylene, 6 x 6 feet, can be spread on the stream bank and substrate materials placed upon it. As the materials begin to dry the animals will abandon their hiding places and can be seen readily as they migrate across the sheet seeking water.

g. U. S. Standard Series No. 30 soil sieves can be used to scoop up fine sediments and sieve out its inhabitants. The entire qualitative sample can also be screened to standardize the organism sizes taken at various sample sites.

h. Any other tools, such as forceps, scalpels, shovels, and forks are legitimate devices and can prove their merit in individual situations.

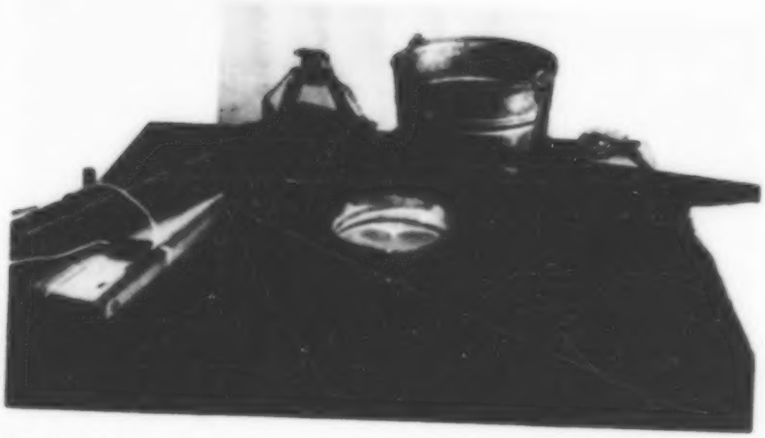

Plate 17. Biological collecting equipment. From left, Kemmerer sampler, Ekman dredge, U.S. Standard No. 30 sieve, washing bucket, and Petersen dredge.

Following these general observations, the investigator collects appropriate quantitative samples of the various kinds of organisms present in the aquatic area. He makes certain that: (1) The sampling area selected is representative of stream conditions, and (2) the sample is representative of and contains those forms predominant in the area and encountered during the qualitative search.

Bottom samples in soft areas usually may be collected with an Ekman dredge, although the physical composition of the bottom determines to a great extent the type of sampler that must be used to collect an adequate sample. The Ekman dredge (Ekman, 1911) consists of a square box of sheet brass 6 x 6 inches in cross section.* The lower opening of this box is closed by a pair of strong jaws so made and installed that they oppose each other. When open, the jaws are pulled apart so that the whole bottom of the box is open; the jaws are held open by chains attached to trip pins. To close the dredge, the trip pins are released by a brass messenger sent down the attachment rope and the jaws snap shut by two strong external springs. The hinged top of the box may be equipped with a permanent 30-mesh screen to prevent loss of organisms if the sample sinks into mud deeper than its own height. The sampler is especially adapted for use in soft, finely divided mud and muck; it does not function properly on sand bottoms or hard substrates. The Ekman can also be mounted on a pipe for shallow stream sampling and tripped by a thrust-through rod.

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* Ekmans are made also in 9" x 9" and 12" x 12" sizes, but because of size of grabs, these are almost impossible to operate effectively on many occasions. Through long experience the author recommends only the 6" x 6" size.

The Petersen dredge (Petersen, 1911) is a most versatile stream bed sampler to collect bottom life. It is widely used to sample hard bottoms such as sand, gravel, marl, clay, and similar materials. It is an iron clam-type dredge, samples an area of 0.6 to 0.8 square foot, and weighs between 35 and 70 pounds depending on the rare use of additional weights that may be bolted to its sides. By means of a rope, the dredge is slowly lowered to the bottom to avoid disturbing and flushing away significant lighter materials. As tension is eased on the rope, the mechanism holding the jaws apart is released. As the rope is again made taut, a sample is secured. The operator controls the dredge by maintaining tension on the rope until the dredge is placed. This is helpful in sampling gravel or rubble, as the operator can determine through sound and touch the type of bottom and by carefully manipulating the dredge, can secure a better sample than would otherwise be possible. In streams with gravel and rubble beds that permit wading, another technique is for the investigator to place the dredge and then stand on the jaws working them into the stream bed with his weight, thus gradually closing them. When the dredge is surfaced, careful and rapid placement and subsequent discharge, endwise, of the dredge into a bucket whose lip is placed at the water's surface prevents loss of material.

The orange-peel dredge is a multijawed, round dredge with a canvas closure serving as a portion of the sample compartment. It is available in a variety of sizes. Its sampling area is a function of depth of penetration and this area must be calibrated, usually with the volume of sediment contents. It has received wide use in marine waters and in the Great Lakes, where it has advantages over other tools for sampling sandy substrates.

The ponar dredge is receiving increased use in deep lakes. In comparative studies it is more efficient than the Petersen dredge when samples are secured from deep (>100 feet) waters. In appearance it is similar to a Petersen dredge but it has side-plates and a screen on the top of the sample compartment.

The Smith-McIntyre dredge has the heavy steel construction of the Petersen, but its jaws are closed by strong coil springs. Its principal advantage is its stability or operator control in rough waters. Its bulk and heavy weight requires operation from large boats equipped with a powered winch.

Core samplers have been used to sample sediments in depth and collect small areas (2-4 sq. inches) of the mud-water interface. Their efficient use requires dense animal populations. Corer design varies from hand-pushed tubes to explosive driven and automatic surfacing models. The Phleger type is the most widely used corer in water quality studies.

It is a gravity corer, relying on its weight (near 100 lbs.) to drive its sample tube into the substrate. The length of core retained will vary with substrate texture; 30 inches is near the maximum length. A core of this length is adequate for most physical, chemical or fossil examination to delineate recent environmental changes.

The Wilding, or stove-pipe, sampler is the only sampler that will quantitatively sample the fauna inhabiting the bottom and/or the vegetation in areas with dense aquatic weed growths. Its operation may be restricted to the vegetation, or mud-water interface sediment may be included.

Drift nets may be suspended in flowing waters to capture invertebrates that have migrated into the water mass from the bottom substrates and are temporarily being transported by currents. Their principal uses have been to study migratory movements and to evaluate sublethal toxicants, especially insecticides, on the fauna. Before toxicants become lethal the animals are weakened and cannot maintain their benthic position and thus are swept away by the currents and carried into the nets.

These nets must be standardized in an individual study. As of now no single style of net has been standardized among investigators. It is recommended that these nets be designed with a 1 x 1 foot upstream opening, with U. S. Standard Series No. 30 netting (or finer, with subsequent screening for uniform organism size), and with a net-bag length of 36 inches.

After suspension in the water, these nets require constant tending. Within a fraction of an hour the nets' efficiency is reduced through clogging of the net by drifting animals and detritus that soon results in significant volumes of water and organisms being diverted around the mouth of the net.

After the bottom sample is collected by one of the deepwater sampling devices, it is brought to the surface and placed in a large pail or tub. Water for sample dilution is added to the pail, and the sample is mixed into a slurry with the slurry finally being passed through a U. S. Standard No. 30 mesh sieve while the sieve is being rotated in the water. The washing operation is repeated until all fine material has passed through the sieve, and all organisms are retained in the sieve. The organisms and coarser debris are then removed from the sieve and are preserved. It is often easier to sort the organisms from the debris when the organisms are alive. Time schedules and extensive field operations, however, often dictate that sample collection and examination take place at different times during the year. Wide-mouthed tapered pint freeze jars, obtainable from most grocery stores, have proven to be excellent bottom organism sample containers. When these jars are filled half full with 10 percent formalin before the day's activities of sample collection, it is a time-saving process to transfer the concentrated sample from the side of the sieve to the jar of preservative by lightly hitting the sieve against the top of the jar. The investigator is assured always of a minimum of 5 percent formalin in the sample container, a sufficient strength to preserve the collected organisms. After the samples are preserved in the field they are returned to the laboratory where the organisms are separated from the debris, placed in respective groups, identified, and enumerated.

To sample riffle areas in streams, a square-foot bottom sampler, originally described by Surber (1936), is widely used. It consists of two 1-foot-square brass frames hinged together at right angles; one frame supports the net which is held extended downstream by current velocities, the other encloses the sampling area. In field operation, the sampler is so placed that organisms dislodged by hand from the substratum within the sampling frame will be carried into the net by the current. In stagnant or in slowly moving water, it often is not practical to employ this square-foot sampler.

In practice, it may be found convenient to remove the larger rocks from inside the sampling frame, placing them in a bucket or tub partially filled with water. Here, the organisms can be washed or scrapped from the rocks, and concentrated by a sieve as described earlier, before being combined with those from the Surber sampler in a sample jar with preservative.

Artificial substrates have been successfully employed in studying bottom-fauna in flowing streams. One multiple-plate sampler constructed of tempered hardboard (Hester and Dendy, 1962) has been especially suitable for studying stream inhabitants in those streams that do not possess a natural substrate suitable for the attachment of benthic forms. A sampler constructed of eight 3-inch squares, separated by seven 1-inch squares, and held in place by a bolt or threaded rod exposes slightly more than 1 square foot of surface to which organisms can attach.

Artificial substrates are placed in the water for 3- to 6-weeks and then carefully removed to prevent losing the organisms that have made them a temporary home. As nearly as possible the substrates should be placed at similar depths and in similar physical relationship to the stream at all stations. Usually they are placed about 1-foot beneath the surface or 1-foot off the stream bed. The multiple-plate sampler can be reduced in size to three plates only and placed vertically near the surface, at mid-depth, and near the bottom at a particular station. Loss of some substrates because of vandalism or flooding should be anticipated.

Periphyton include the assemblage of organisms that grow on free surfaces of submersed objects in water and cover them with a slimy coat.

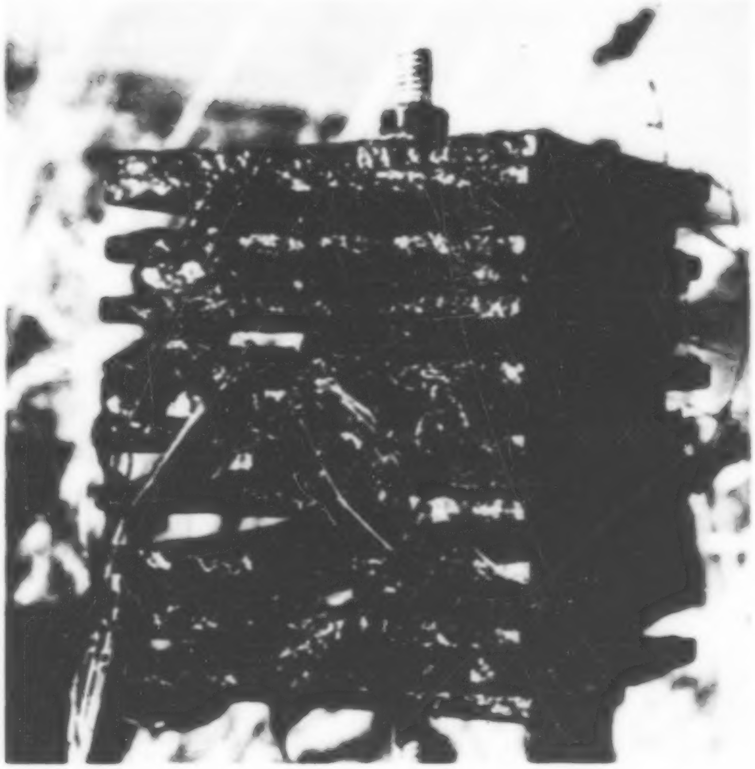

Plate 18. A multiple-plate artificial substrate colonized by aquatic organisms (Hester-Dendy type)

Cooke (1956) comprehensively reviews the literature on the subject. Periphyton play an important role in flowing waters because these organisms are the major primary producers in that environment. Thus, they are an important part of a lake or reservoir study of both the influent and receiving streams. A number of substrates have been proposed with which to study attached organisms including glass slides, cement blocks, wooden shingles, and plexiglass plates (Grzenda and Brehmer, 1960). Growths on such substrates may be analyzed qualitatively or quantitatively.

The type of artificial substrate employed to collect organisms is not terribly important as long as the same type is used at all such sampling stations in a particular investigation. Any type will be somewhat selective to those organisms that are attracted to it. They do tend to favor drift organisms or those that become detached from their dwelling areas and float downstream with the current. When the same type of sampler is used at each station, data collected among the stations should be comparable.

Patrick et al. (1954) developed a slide-carrying device, termed the Catherwood Diatometer, to sample the diatom populations of streams. It consists of a plastic base mounted on a lead bar shaped like a boat. On the plastic base are mounted two floats designed so that the depth to which the diatometer is sunk can be varied. Between the floats, behind a plastic V-shaped vane, the plastic slide holder slotted to hold six slides vertically is mounted edgewise to the current. The vane prevents excess washing of the slides. It was stated that 1 week was sufficient to expose the slides and that the population of an unpolluted stream could be estimated as adequately with this method as with the usual methods of collecting diatoms. Calculations upon which these estimates are based must be corrected when dealing with polluted streams.

A comprehensive review on limnological methods to investigate periphytic communities has been prepared by Sladeckova (1962). She lists 418 references as a bibliography and portrays a large number of devices on which attached organisms can grow and be sampled. In a summary she states that there is no single, universal method for the quantitative evaluation of periphyton for every purpose. An analysis of ecological factors influencing the periphytic community may make methods for the evaluation of this community on natural substrata preferable. On the contrary, the use of artificial substrata is essential for the determination of periphyton formation on a unit area or for the study of colonization and stratification of attached organisms, especially in deep water. The choice of exposure technique is often determined by circumstance. The duration of exposure must be tested in advance. Lund and Talling (1957) completed an earlier review with 777 references; they also discussed methods with special reference to algae, both planktonic and attached. Sladecek and Sladeckova (1964) discussed the glass slide method for the determination of periphytic production in particular. Methods were cited for the calculation of production rates.

In the study of attached organisms in waters receiving acid mine drainage, it was found that extreme corrosion of the slide holding device contributed to a substantial loss of samplers during the study period. A type of putty (Plasti-tak[*]) has been found to be extremely useful to secure microscope slides to clay bricks or to the upper fiber board plate of a multiplate sampler (Thomas, 1968). Advantages to this procedure include good holding power, noncorrosive aspects in acid or salt water, ease of artificial substrate placement, low cost, and removal of single slides without disturbing adjacent ones. The surface to which the adhesive is applied must be dry and clean and the adhesive will release in fast water after about 3 weeks.

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[*] Mention of a commercial product does not constitute endorsement by the Environmental Protection Agency.

To obtain a history of sediment deposition or to permit selection of strata within the sediments, sampling of these by a commercial core sampling device is expedient. Much information of a historic nature can be obtained and can be related to the problem under investigation through the chemical and biological examination of sediment cores.

Samples collected for plankton analysis are most often similar to those collected for the analyses of chemical water quality. They may be collected with the aid of a Kemmerer sampler or similar device that permits capture of a sample from a particular water strata.

Fish samples may be collected by nets, seines, poisons, and electrofishing. Electrofishing is conducted by means of an alternating or direct electrical current applied to water that has a resistance different from the fish. This difference in resistance to pulsating direct current stimulates the swimming muscles for short periods of time, causing the fish to orient and be attracted to the positive electrode. An electrical field of sufficient potential to demobilize the fish is present near the positive electrode, but decreases in intensity with distance. After the fish are identified, weighed, and measured, they can be returned to the water uninjured.

The electrofishing unit may consist of a 110-volt, 60 cycle, heavy duty generator, an electrical control section, which is a modified commercially sold variable voltage pulsator, and electrodes. The electrical control section provides selection of voltages from 50 to 700 volts a.c. and 25 to 350 volts d.c. The a.c. current acts as a standby for the d.c. current and is used in cases of extremely low water resistance. The variable voltage allows control of field size in various types of water.

Meaningful samples of littoral vegetation may be difficult to secure. Sampling, per se, is often not necessary. It is usually sufficient to map, identify, and estimate abundance of the principal components of the aquatic vegetation population.

Sample Analyses

When samples are collected of animals associated with the lake or stream bed the organisms and debris are usually preserved with 10 percent formalin. The formalized sample is washed in the laboratory to remove the strong formalin solution. From this point it is necessary to remove and segregate the animals on which an interpretation will be made from the debris within the sample jar. A number of flotation methods have been proposed by various authors to reduce the time expended in this operation. When an investigation includes stream reaches that are heavily polluted with organic sludges or that produce prolific growths of slimes and other attached organisms, flotation methods do not work well. Thus, as a routine measure the somewhat laborious effort of separating organisms from debris through hand sorting must be employed.

A white enamel pan with a depth of approximately 1½" is often used in the hand picking operation. It is convenient to fill half the pan with water and then place 2 or 3 tablespoons of material from the sample jar in the center of the pan. By teasing the sample to all sides with the aid of forceps, small animals can be removed without difficulty. It is helpful for later identification to keep the removed organisms separated into the taxonomic groups that are discernible with the unaided eye. When it is noted that organisms within the collected sample are limited to a few (2 to 4) kinds and are extremely abundant as they often are when sludgeworms reproduce in great numbers in organic sludge, samples may be split to reduce time and labor in removing organisms. This is accomplished by placing the sample in the white pan without water, leveling the sample surface, and randomly selecting ½, ¼, $\frac{1}{16}$, or $\frac{1}{32}$, of the sample for organism removal. When this is done, the entire sample should be examined for those larger organisms that may not be numerous. In reports written principally for those outside of the biological discipline, bottom fauna abundance is expressed usually as the number of a particular kind of organism per square foot. Organisms from 6" x 6" Ekman dredge samples, for example, would be multiplied by 4 to arrive at the number per square foot. When the sample is split and only an aliquot examined, the appropriate conversion multiplication must also be used. Further identification through the use of a stereoscopic microscope and counts to ascertain numbers within a particular group are made to facilitate interpretation of water quality.

Slimes and other attached growths are identified and estimates made of relative abundance. Quantitative methods are often employed. Chlorophyll determinations may be used as an indicator of those plants that possess this material and the determination is often helpful to separate attached algal quantities from slimes.

Chlorophyll, an enzyme present in green plants, in the presence of light converts carbon dioxide and water to basic sugar, a process that is termed photosynthesis. Chlorophyll increases in lakes as the lakes become more eutrophic; thus chlorophyll measurements provide comparative data on eutrophication.

Chlorophyll-bearing cells may be filtered from the water with membrane filters (0.45 micron pore). Filters and cells are placed in vials of acetone for extraction of the pigments and for solution of the filters

(Creitz and Richards, 1955). Samples are then centrifuged to remove particulate suspended materials. The clear supernatant pigment-bearing acetone is examined on a recording spectrophotometer. Spectrums are evaluated and the quantity of chlorophyll determined as outlined by Richards with Thompson (1952).

Some waters contain sufficient plankton (phyto- and/or zooplankton) so that samples must be diluted to obtain adequate numerical information; however, with a sparse plankton sample, concentration should be used. The phytoplankton in samples from most natural waters require neither dilution nor concentration and should be enumerated directly. Correspondingly, zooplankton often are not sufficiently abundant to be counted without concentration. Selection of methods and materials used in plankton enumeration depends on objectives of the study, density of plankters in the waters being investigated, equipment available, and experience of the investigator.

The Sedgwick-Rafter cell has been and continues to be the most commonly employed device for plankton enumeration because it is easily manipulated and provides reasonably reproducible information when used with a calibrated microscope equipped with an eyepiece measuring device, usually a Whipple ocular micrometer. It can be used to enumerate undiluted, concentrated, or diluted plankton samples. The biggest disadvantage associated with the cell is magnification. The cell cannot be used for enumerating very small plankton unless the microscope is equipped with special lenses that provide sufficient magnification (400 × or greater) and clearance between objective lenses and the cell.

The Sedgwick-Rafter cell is 50-mm. long by 20-mm. wide by 1-mm. deep. Since the total area is 1,000 mm.^{2}, the total volume is 1×10^{12} cubic μ, 1,000.^{3} or 1 ml. A "strip" the length of the cell thus constitutes a volume 50-mm. long, 1-mm. deep, and the width of the Whipple field. Two or four strips usually are counted, depending on the density of plankters. Counting more than four strips is not expedient when there are many samples to be enumerated; concentrating procedures then should be employed, and counts made of plankters in the concentrate.

$$\text{No. per ml.} = \text{Actual Count} \times \frac{1{,}000}{\text{Volume of ``Strip'' (mm.}^3\text{)}}$$

If the sample has been concentrated, the concentration factor is divided into the actual count to derive the number of organisms per ml. For separate field counts (usually 10 or more fields):

$$\text{No. per ml.} = \text{avg. count per field} \times \frac{1{,}000}{\text{Volume of field} \times \text{No. of fields}}$$

When special lenses are not used and there is a need to enumerate small plankton, unusually abundant, other procedures may be employed in conjunction with and related to counts obtained from the Sedgwick-Rafter cell.

Lackey (1938) used a drop counting method in his examination of Scioto River, Ohio, phytoplankton. In this method, the sample is first centrifuged and ". . . after thorough agitation by alternately sucking it in and spurting it out of the pipette, the exact number of drops was counted and a sufficient number of drops of the decanted portion was added, so that one drop of catch bore a definite relationship to the amount centrifuged." One drop of sample is put on a glass slide and a cover glass added; 5 low-power fields and 10 high-power fields are examined and the number of each species is recorded at the magnifications used. Enumeration is repeated on 3 such mounts for a total of 15 low-power fields and 30 high-power fields.

No. per ml = avg. no. per field × no. of fields per drop or per cover slip × no. of drops per ml ÷ the concentration factor.

The concentration factor = ml of original sample ÷ ml of concentrate × (100 − percent of preservative in sample).

Lackey's method has the advantages of including all organisms in the catch, simplicity and ease of manipulation, and instant use of the high power magnification where identification with the low power is questionable. Certain disadvantages are inherent in the method: (1) because water normally is used as a mounting medium enumeration must be accomplished relatively rapidly to prevent dessication and subsequent distortion of organisms; (2) results are not sufficiently accurate when only one slide-mount is examined thus, it is necessary to prepare and enumerate at least three or more slide-mounts; and (3) the investigator should be sufficiently familiar with plankton to rapidly identify and count the specimens encountered.

Plankton samples have been successfully concentrated by settling with a liquid detergent and counted by the drop technique. To concentrate the phytoplankton, 500 ml. of sample were placed in 1-liter glass settling cylinders to which were added 20 ml. of commercial formalin to preserve the sample, and 10 ml. of a detergent to settle the sample. Sedimentation of the plankton was complete in 24 hours, after which the supernatant was carefully siphoned from the cylinder, and the concentrate was washed into screw-capped storage vials and brought to the nearest 5 ml. by the addition of 4 percent formalin and the use of a volume standard. In making the drop count, 5 low-power fields and 10 high-power fields were observed on this slide, and the magnification as well as number of each species of organisms was recorded. This procedure was repeated on 3 such mounts so that totals of 15 low-power fields and 30 high-power fields were observed. The number of a particular type of organism in 1-liter of water was determined by the following formula:

$$\text{No./l} = \frac{(\text{Avg No./field})\,(\text{No. fields/coverslip})\,(\text{No. drops/ml}) \times 1{,}000}{\text{Concentration factor}}$$

$$\text{The concentration factor} = \frac{\text{ml. of original sample}}{(\text{ml. of concentrate})\,(0.94)}$$

where 0.94 accounts for the dilution of the sample by the addition of formalin and the detergent.

The average volume in cubic microns of each species was obtained by measuring 20 individuals. The volume contributed by each species was expressed in parts per million by use of the following formula:

$$\text{Volume (ppm)} = (\text{No. org/l})\,(\text{avg species vol in } \mu^3) \times 10^{-9}.$$

Segments of lake bottom core samples may be analyzed microscopically to determine the diatom composition of the layered segments. To examine diatomaceous sediments in lake bed core sediments, an aliquot solids sample based on a packed volume of a selected core segment is oven-dried, suspended in equal parts of water and concentrated nitric acid, gently boiled for 45 minutes, and allowed to cool. Potassium dichromate crystals (0.1 gram) are added, the mixture cooled, washed into a centrifuge tube, and water added. The sample is washed 3 times by alternately centrifuging, decanting, and adding water. The inorganic residue is then diluted to a specific volume of water (200 ml. per gram of original sample), then 2 drops of liquid household detergent are added, the sample is stirred, and 2 drops of sample are withdrawn by a large bore pipette and placed on a cover slip. The sample on the cover slip is evaporated to dryness on a hot plate. Following drying the hot plate temperature is increased to 350°F, a clean microscopic slide is placed thereon, and a large drop of suitable microscopic mounting media such as Harleco * or Styrax * is placed on the slide. After 10 minutes, with slight cooling, the cover slip with the dried sample is inverted onto the mounting medium drop and pressed firmly into place. The slide is then examined for diatom skeletons.

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8

Stream Surveys

Study Plan

ANY field investigative technical study should be preceded by a study plan. A study plan, which should be recorded in writing, should delineate the steps taken in preparing for and conducting a study. The study plan begins with a clear **STATEMENT OF THE PROBLEM** or need that prompted the investigation. It should include a description of the problem, the importance of resolving the problem, the requestor for the study, and the previous actions that have been undertaken to resolve the problem.

The statement of the problem is followed by a clear statement of **AUTHORITY** for conducting the study. **STUDY OBJECTIVES** should follow with clear, concise, positive definitions of the investigation's purpose, its scope, and its limitations. Study objectives provide a basis for judging the extent to which the results of the study meet the needs that justify the undertaking. The next sequential step in developing a study plan is to identify the **APPROACH** of the investigation. The approach contains a definition of the boundaries and location of the study area and a map showing proposed sampling stations, approximate distances, and other pertinent features. A description of sampling or of data collection is included, which indicates the projected inclusive dates of field sample collections, the types of samples to be collected, the locations from which samples will be collected, the periodicity of sample collection, the number of replica samples for particular sampling types, the general method of sample collection, and the number of sampling cruises necessary to complete the collection. Data collection is followed by a statement on laboratory analyses including the kinds of analyses to be performed, the use of fixed or mobile laboratories, and the availability of laboratory facilities. A statement on any special equipment or facilities that will be needed for the study should include its availability and location. A work schedule or a timetable showing each major project task, or a study division, with the starting and finishing dates for the completion of the task should be included. Lastly, the study plan should define **RESOURCE LEVELS**, which include an itemization of the estimated expenses for the study, an indication of manpower needs by a project task, and a statement regarding the need for any manpower in addition to that readily available.

In conducting a stream study it should be understood by the investigator that a stream's physical characteristics greatly influence its reaction to pollution and its natural purification. An understanding of the nature of these influences is important to the intelligent planning and execution of stream studies. Important physical factors include temperature, turbidity, depth, velocity, turbulence, slope, changes in direction and in cross sections, and nature of the stream bed. These factors are closely interrelated and acting either separately or together they influence the type of life that will become and remain associated with the water.

Wastes Mixing

Wastes entering a stream mix vertically, from top to bottom, laterally from one side to the other, and longitudinally from their point of entrance to a point downstream. The distances that wastes mix in these three directions must be considered in selecting appropriate sampling stations. The vertical mixing of wastes in a stream is usually rapid and enhanced by turbulence, which may cause vertical mixing to be completed within a few hundred feet. Lateral mixing is generally depended on the occurrence of relatively sharp reverse bends within the stream, and the distance for adequate lateral mixing across the stream may be in miles. Longitudinal mixing also is in terms of miles or perhaps days of stream flow. The water passing a point downstream from a waste source is not the identical mass of water that passed the waste source at some specified earlier time. Instead it is a mixture of particles of water that passed the waste source at different times and spent various times in traveling to the downstream sampling point. Such variations ultimately are averaged-out at some distance down the stream to produce uniform concentrations of waste constituents throughout a 24-hour period.

Waste Sources

There are a great number of different kinds of waste sources that influence water quality and life within the receiving waters. Municipal sewage, industrial wastes of all varieties, acid mine drainage, heat pollution, agricultural wastes, wastes from confined animal feeding areas, logging practices, irrigation return flows, construction site siltation, waste from ships and other vessels, and general land runoff all contribute to water quality degradation. Information on some of these wastes sources is known and can be obtained from the appropriate governmental or other agency.

Pertinent information on the quality and quantity of sewage inflows can be obtained usually from the municipality operating the plant if the State water pollution control agency has no data or if the data are insufficient for the purposes of the investigation. Some approximation for purposes of calculation may be useful in defining the sewage load for a given plant. For example, the number of connected homes multiplied by 3.7 persons per family gives a reasonable estimate of the sewered population. The sewered population multiplied by 0.17 pounds of 5-day biochemical oxygen demand (BOD) per person per day provides an estimate of the BOD load of raw domestic sewage. The sewered population multiplied by 0.2 pounds of suspended solids per capita per day is an estimate of the suspended solids load of the raw sewage. The total coliform bacterial load in the receiving stream, if no treatment is provided, may be estimated by multiplying the sewered population by 400 billion per capita per day for temperatures above 15° centigrade and 125 billion for temperatures below 15°C. The population equivalent for total phosphorus is approximately three pounds (P) per capita per year and that of total nitrogen approximately nine pounds per capita per year.

An estimate of the treated sewage BOD load may be made by applying conventional percentage reductions in BOD for various types of treatment if an estimate of the raw sewage load has been made. Values used commonly are 33 percent reduction for primary treatment, 65 percent for chemical precipitation, and 85 percent for a secondary treatment such as trickling filter plants and about 90 percent for activated sludge plants. Reductions in suspended solids by conventional treatment may be estimated as 55 percent for primary, 80 percent for chemical precipitation, 80 percent for trickling filter plants, and 90 percent for activated sludge plants. Bacterial reductions may be estimated as 50 percent for primary treatment, 60 percent for chemical precipitation, between 92 and 95 percent for secondary treatment plants, and 99 percent for chlorination following secondary treatment.

If greater reliability than that of an estimate is required for the particular investigation this type of measurement of the sewage load to the receiving waterway can be achieved only by round-the-clock sampling because of the wide variation in flow and sewage constituents from the mid morning maximum to the minimum of early morning hours. Raw sewage should be sampled frequently, possibly every 10 to 15 minutes because of its variability. Plant effluents may be sampled less frequently, possibly every 30 minutes to 1 hour. Flow measurements are necessary to determine the quantity of pollutional load and to composite the samples collected in proportion to the flow at the time of sampling, if a compositing method is used.

Industrial wastes are even more capricious than municipal wastes. In their composition throughout a period of time, industrial wastes may vary significantly in their constituents with different manufacturing processes that may be begun and stopped periodically. Thus, the knowledge of the industrial process producing a given waste is essential to predict the potential characteristics of the waste water. An appropriate sampling schedule must be developed that will include the variations in waste water constituency, as well as flow. The time of operation of the industry must be taken into account in such a sampling program. Some plants operate 8 hours a day, some 16, and some 24.

The sampling of non-point waste sources, including many of those wastes associated with agricultural practices as well as construction, must be designed to fit the situation being studied. Many of these waste waters are associated with periods of intense precipitation and land runoff, thus, they become intermittent rather than continuous discharges. Some information is available in the literature regarding the composition of confined feedlot drainage, irrigation return flows, and general land drainage from fertilized crop lands. The predominant soils of the area have a significant impact on the characteristics of the runoff. The difficulties of obtaining a quantitative determination of non-point source inflows are paramount. A method that frequently is used includes sampling the receiving waterway at points both upstream and downstream from the area that is being assessed for non-point source pollution potential and ascertaining the difference between the two stations so sampled. It is, of course, axiomatic that no significant point source waste be present to obfuscate the results of such a determination. If a point source waste is present, and its pollutional load is known, this load may be subtracted from the difference between the two stations designed to depict the loading of non-point sources to arrive at the correct answer to the investigative problem.

Water Use Considerations

The underlying purpose of a water quality study often is to determine the effects on uses of the water involved. A knowledge of existing and potential water uses is therefore essential to the intelligent planning of a water quality study. Cognizance should be given to water uses in the placing of sampling stations. Generally the water use that requires the highest water quality will dominate the formulation of the recommendations resulting from a water quality investigation.

Water uses include those for municipal water supplies; industrial water supply; agricultural water supply, including livestock watering, irrigation, and domestic farm use; recreation, including swimming, wading, water skiing, boating, and aesthetic enjoyment; the propagation of fish and other aquatic life and wildlife, including sport fishing, commercial fishing, fur trapping, and as a water supply for wildlife; hydropower production; and navigation. Different water uses require substantially different water qualities. Those uses that require the highest water quality from the standpoint of chemical and microbiological constituency include the uses for fish and other wildlife, recreation, and municipal water supply.

Station Location

The selection of stations for stream sampling of chemical characteristics is dependent upon judgments derived from an assessment of the physical characteristics of the stream, as well as the predicted mixing qualities of inflowing pollutants. As Kittrell relates in his 1969 book that was cited as a basic reference in Chapter VI, the ideal sampling station would be a cross section of a stream at which samples from all points on the cross section would yield a similar concentration for each particular constituent, and a sample taken at any time would yield the same relative concentrations as one taken at any other time. A marriage of these two conditions to produce the ideal sampling stations never persists in nature for any appreciable time period. Variations in water quality with time require that samples be collected at the proper frequencies and times of day to ensure results representative of the quality variations.

Seldom is it necessary to sample at various depths in a stream because of incomplete vertical mixing. Sampling usually is at either a 5-foot or mid-depth whichever is lesser, except for certain biological samples such as plankton that may be sampled at a depth of about 1-foot or bacteria that is usually sampled just beneath the surface. Lateral mixing on a stream poses yet another problem and it is good practice to take samples at quarter points across the stream unless a predetermination of mixing has shown that a single sample at mid point of the main current is adequate.

Samples should be obtained from major tributaries. As a general rule, tributaries with flows greater than 10 to 20 percent of that of the main stream should be sampled. Tributaries with lesser flows should be included if they are suspected of being significantly polluted. Should the principal interest center on the main stream, the sampling of tributaries at their mouths may be adequate. It is often desirable however to pinpoint the source of waste inflow on the tributary and to determine its loading in pounds per day in a similar fashion to that of a waste inflow on the main stream. The determination of the quality of waste inflow involves an assessment of waste constituent concentrations, as well as a gaging or a determination of the volume of waste flow. Usually there is a variation in waste strength throughout a 24-hour period and this variation must be detected and considered in determining the pounds per day contribution. Similarly, an appraisal must be made of the flow within the receiving waterway to relate the pounds of dissolved

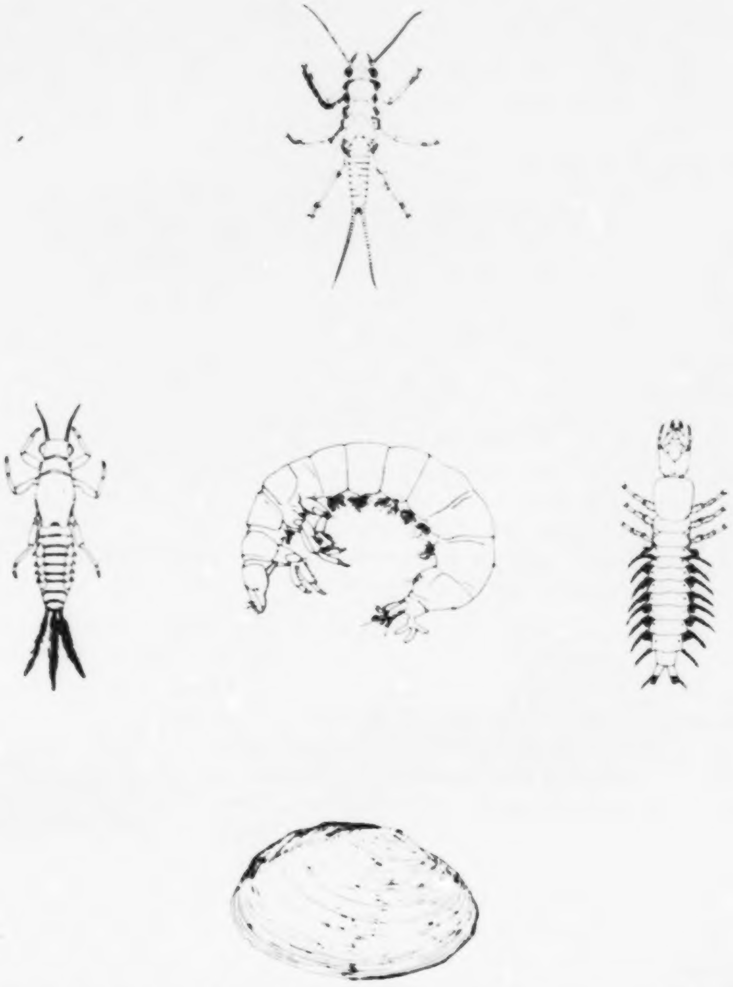

Plate 19. Representatives of stream bed associated animals [The clean water (Sensitive) group]. From left: Stonefly nymph; Mayfly naiad; Caddisfly larvae; Hellgrammite Unionid Clam.

oxygen that may be used, for example, with the pounds of biochemical oxygen demand that may be contributed by inflowing wastes.

Usually a series of sampling stations are selected on a stream to establish a course of pollution or water quality change throughout a given reach of river. When time-of-water travel determinations can be made, a desirable interval for station selection is about one-half day time-of-water travel for the first three days travel below a source of waste, and about one day throughout any remaining distance. On small streams that may be quite heavily polluted the location of longitudinal sampling stations should be at a much closer interval if one is to assess the damage of the waste load from an analyses of chemical constituents. Major points of water use, including recreational and water supply areas, should be included in the sampling regime.

Personnel and facility limitations may prevent the collection of samples from all stations or points for the examination of the desirable daily number of samples. The least detrimental cut in projected sample numbers can be made in the number of stations when reduction of the sampling or analytical program below the optimum level is necessary. Decreasing the number of stations in a stream reach by increasing the spacing between them usually is preferable to reducing the lengths of the reach, the number of points on station cross sections where lateral mixing is incomplete, or the frequency or total number of sampling runs.

Biological sampling stations to assess the stream environment routinely should be located close to or at those sampling stations selected for chemical and microbiological analyses to enhance interpretation of water quality through the use of interrelated data. Sampling stations should be located upstream and downstream from suspected pollution sources, from major tributary streams, and at appropriate intervals throughout the stream reach under investigation.

The upstream or control station or stations should depict conditions unaffected by a pollution source or tributary. The nearest station downstream from the pollution source or tributary should be so located that it leaves no doubt that conditions depicted by the sample can be related to the cause of any environmental change. The minimal number of downstream stations from this point should be located in the most severe area of the zone of active decomposition, downstream in an area depicting less severe conditions within this zone, near the upper upstream reach of the zone of recovery, near the downstream reach of the recovery zone, and in the downstream reach that first shows no effect from the suspected pollution source. Precise station locations will depend on the flow, the strength, volume, and type of pollution entering the source and the entrance of additional sources of pollution to complicate the stream recovery picture. When water in tributary streams is found to be polluted, or to influence water quality in a primary stream, these streams should be similarly investigated. The precise location of sampling stations can be aided through a cursory examination of the benthic fauna, which are excellent indicators, as a community, of prevailing water quality.

A stream usually is composed of riffles and pools. These areas will vary in depth, velocity of flow, and types of substrate that form the

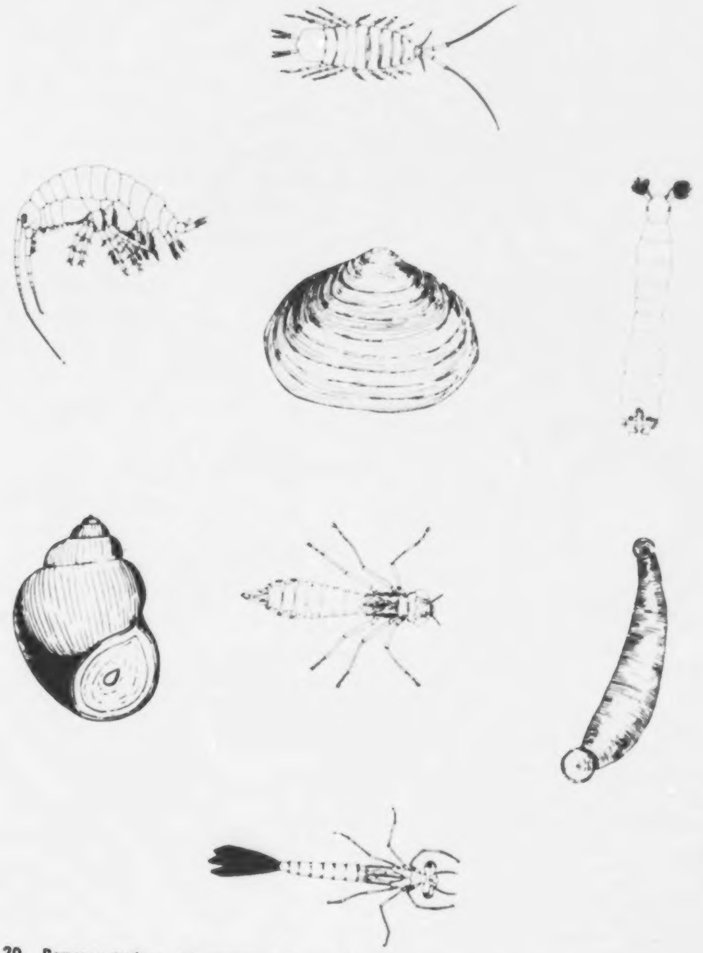

Plate 20. Representatives of stream bed associated animals (The intermediately tolerant group). From Left: Scud; Sowbug; Black fly larvae; Fingernail Clam; Snail; Dragonfly nymph; Leech; Damselfly nymph.

stream bed. Because a biologist seeks to determine changes that occur in water quality as depicted by aquatic organisms, and to relate the changes to particular sources, he must compare observations at a particular station with observations and findings from an upstream station, as well as with those at a station within the stream reach that is unaffected by a suspected source. To accomplish this, an effort should be made to collect samples from habitat types that are morphometrically similar. Riffle samples should be compared with riffle samples and pool samples compared with pool samples. Both should be studied in a stream where feasible to determine the extent of each major environmental change produced by pollution. The biological investigator may need to choose a number of stations in addition to those selected for routine chemical or bacteriological sampling to access satisfactorily the extent of biological change.

Plankton samples are collected usually at one point within the study station, most commonly at mid stream 1- to 2-feet below the surface.

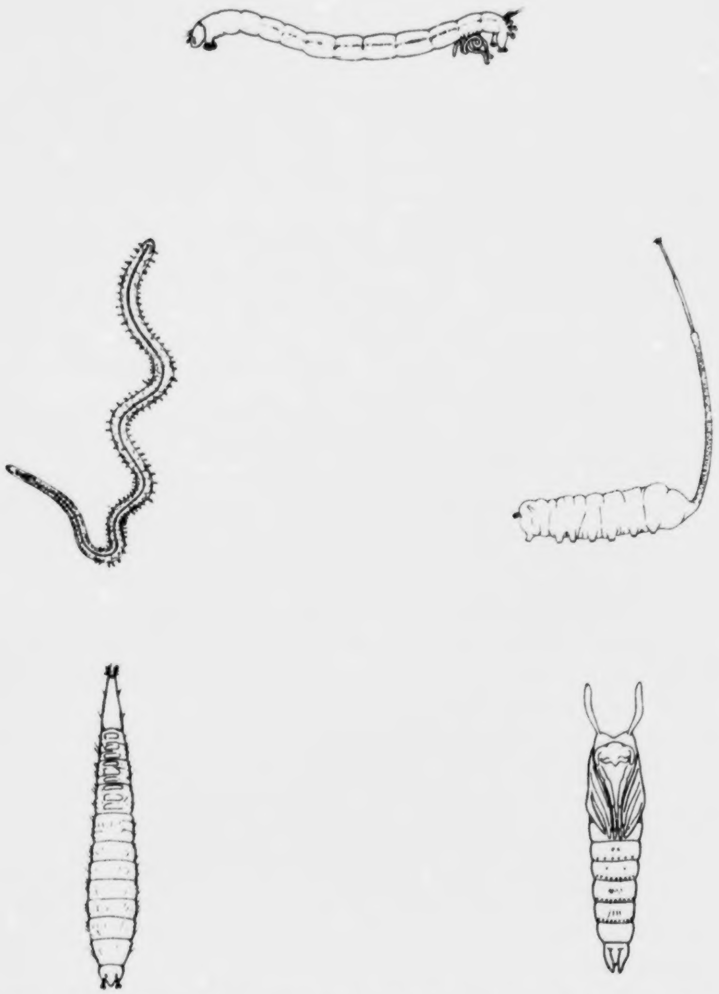

Plate 21: Representatives of stream bed associated animals (The very tolerant group). From left: Bloodworm or midge larvae; Sludgeworm; Rat-tailed maggot; Sewage fly larvae; Sewage fly pupae.

Samples for bottom-associated organisms should be collected at a number of points on a transection between the stream banks. Optimistically, these samples should be collected at a minimum of five points across the stream (mid and 2 quarter points and at near zero water level with banks). More than one sample may at times be collected from each point and retained separately. Realistically, the objectives of a particular survey and the number of stations at which bottom fauna are collected may dictate the number of samples for a particular station. Attached slimes and other growths are sampled as they occur and when it appears that a change has taken place within the community of attached organisms.

Samples for bacteriological examinations must be collected in bottles properly sterilized and protected against contamination. The preferable method is to scoop up the water with the open bottle just beneath the surface. This method usually is used when sampling by a boat. When sampling from a bridge, the sterilized sample bottle should be placed in a weighted frame that holds the bottle securely. While the bottle is open, both bottle and stopper must be protected against contamination. A small amount of water should be poured from the bottle after filling to leave an air space for subsequent shaking in the laboratory. The bottle should be closed at once and analyzed expeditiously.

Sampling Periodicity

Frequency of sampling varies with the water use, the urgency of developing a representative record of quality, and the resource capability of the investigative team. Sampling usually is done at least daily for an operating water supply and may be taken at random or systematically alternated throughout the operating day so that the sample will not represent fixed daily time. In the larger water treatment plants, sampling of raw water may be more frequent and as often as once each shift, or even hourly. Weekly collections, as a minimum, are desirable throughout the season of active biological growth to measure planktonic populations and chemical constituents that may change rapidly. In special studies, samples are often collected daily or even periodically during a 24-hour day to assess these changes. During the non-growing season monthly samples of these constituents should be adequate except where otherwise indicated by the objectives of the study. A reconnaissance and mapping of the aquatic vegetation should be done during maximal vegetative growth, usually in mid or late summer.

Selecting the seasonal time of year to institute a field study is an important and significant consideration in ensuring that the data collected will depict representative conditions of water quality. Generally, the most severe conditions for life in water occur when temperatures are increased by the heat of summer and when stream flows are at a minimum. This may correspond with the maximal growth of planktonic or attached plants, which release oxygen to the water during the sun-lighted photosynthetic period and remove oxygen from the water during the night time plant respiration period. Another seasonal time when conditions of existence for life in water are at a minimum occurs during late winter just before ice breakup in those streams and other waterways that are ice-covered in northern climes. Ice and snow preclude sufficient sunlight from reaching the water to trigger photosynthetic oxygen production and, when organic materials are present, the available dissolved oxygen is slowly removed from the water by the bacteria during the decomposition of these materials. If wastes enter the stream that are high in sugars, biological slimes develop in profusion and further reduce the available oxygen through decomposition processes.

If one is interested in demonstrating the most severe effect on water quality and associated aquatic organisms, it may be sufficient to sample the waterway only during the low stream flow period of late summer or early fall. In northern areas, additional samples to complement the study should be taken during the late winter just before ice breakup. Complex water pollution investigations on major waterways require greater sampling efforts and usually are investigated for periods of time during each of the prevailing seasons for the area. The collection of generally 20 samples for chemical analyses from a particular station for each of the periods of sampling should give an adequate data base from which to reach a conclusion on water quality for that period of time. Of course, if the variation in a specific determination among samples is great, the number of samples necessary to reach a valid conclusion is increased.

Insect representatives of the bottom organism community emerge from the water as adults periodically throughout the warm weather. Times of emergence depend on the species involved. Life histories of these organisms tend to overlap so that at no time is there a dearth of such organisms within the bottom-associated community. Bottom fauna should be sampled during the annual seasons whenever possible. The standing crops of benthos will be highest however during the fall and winter period when insect emergence is minimal. One of the sampling times should represent this season.

Because of the report deadline or limited resources available, the theory and practice of station location and sampling periodicity may not coincide. The objectives of a study may be met by investigating only bottom fauna and attached organisms in a stream and these on perhaps only one occasion during the time of most critical temperature and stream flow. Much can be learned from this minimal effort. The effect on aquatic life can be predicted but no information will be obtained on the quantity of pollutants entering or within the stream, and the amounts that must be removed before aquatic life will regain the population that would be expected during conditions when pollution was virtually absent.

Investigators should be careful not to burden the sampling program with more than the kinds and numbers of samples and analyses that will be required to meet the stated objectives of the study. For example, little knowledge may be gained from only one series of plankton samples from a stream. Because these organisms are carried by the currents a given sample is representative of water quality at some point upstream rather than at the place of sampling.

Laboratories

The conduct of any field water quality investigation involves the necessity of sample analyses at a laboratory. The laboratory in question may be of the fixed type at some distant point where precision instruments are available. In this event, consideration must be given to the physical problems of transporting the samples from the site of collection to the analytical laboratory bench. Mobile laboratories have been used successfully by many governmental agencies in the examination of water quality. These are self-propelled usually or of a separate trailor

Plate 22. Analyses in a wet chemistry laboratory of samples collected from a field investigation.

type that requires a tractor to move the laboratory from place to place. Mobile laboratories have been designed to include all of the essential analytical equipment, as well as air conditioners, dishwashers, and other essential conveniences for the analyst.

The investigator should keep the laboratory analyst informed at all times of any changes that may occur in the field investigation. He should become particularly cognizant of the daily analytical work load that can be performed without undue stress on the part of the laboratory analyst. The analyzing of samples from a field study is a highly repetitive type of operation and, for greatest efficiency, a day's field collection from the chemical and microbiological stations must fit conveniently in the analytical work day within the laboratory. Samples collected for plankton and benthic organisms, on the other hand, can be preserved for a period of time and examined at a later date. Often it is not essential that these be returned to the laboratory immediately and such samples collected during a field investigation may be retained in the field headquarters until the end of the survey before being transported to the laboratory. When there is no urgency for a report of the field investigation, it is often convenient to collect such biological samples during the summertime "field" season and examine such samples during the winter months when climatic conditions are more inclement for sample collection.

9

Pond and Lake Investigations

STEPHEN A. Forbes, writing in the Illinois Natural History Survey Bulletin in 1925, described in colorful and eloquent prose his concept of the lake environment with the words:

> "A lake is to the naturalist a chapter out of the history of primeval time, for the conditions of life there are primitive, the forms of life are, as a whole, relatively low and ancient, and the system of organic interactions by which they influence and control each other has remained substantially unchanged from a remote geological period.
>
> "The animals of such a body of water are, as a whole, remarkably isolated—closely related among themselves in all their interests, but so far independent of the land around them that if every terrestrial animal were suddenly annihilated it would doubtless be long before the general multitude of the inhabitants of the lake would feel the effects of this event in an important way. It is an islet of older, lower life in the midst of the higher, more recent life of the surrounding region. It forms a little world within itself—a microcosm within which all of the elemental forces are at work and the play of life goes on in full, but on so small a scale as to bring it easily within the mental grasp."

The Pond as a Study Habitat

The preceding chapter was devoted to a study of the flowing water environment. It should have been readily apparent that such a habitat would prove to be an excellent laboratory for a class project for the high school or early college curriculum. The possibility exists for an attack on the investigative problem by individuals with a wide variety of personal scientific interests and the amalgamation of the data collected into a useful report aimed toward actions to correct the prevailing problems. The stream environment presented an ever-changing panorama of life and chemical conditions as the water flowed downstream and was affected by various physical conditions and the entrance of a wide variety of pollutants that may act individually or in combination to produce various and sometimes complex effects.

As a study project, the confined pond or small lake environment with its multiplicity of biotic interactions offers an entirely different type of habitat from the stream environment. The pond or lake environment offers a stimulating and interesting study for a variety of scientific disciplines; it is a confined area where much effort can be concentrated in one geographical site thus precluding certain transportation problems associated with some investigations. Further, the intricacies of the microcosm of life that Professor Forbes referred to in his 1925 writing will probably take a longer period of time to define and should be more challenging to the investigator than that of the flowing water environment.

Being confined, life within a pond or lake is not subjected in the same degree to sudden environmental changes as is life in the flowing water environment. There is a buffer zone between the environmental insult and the remainder of the standing water ecosystem. Life's vicissitudes occur less rapidly in a pond compared to a stream.

The Standing Water Environment

A complex interaction of many physical, chemical, and biological factors, influenced by meteriological phenomena, occur in the standing water environment. Nutrients are vital as a food supply for the ecosystem and dissolved oxygen is an essential component for aquatic life. Changes in the concentration of either of these factors will induce significant alterations in the complexity of life that inhabits the water. The pond or lake environment tends to be a vertical environment as contrasted with the more horizontal environment of the flowing stream. Because of this, factors such as temperature and light penetration assume roles of paramount importance and become controlling conditions to life in the vertical environment.

Water weighs 62.4 pounds per cubic foot or 8.345 pounds per gallon at 4°C (39.2°F). It is approximately 0.2 lb. per cubic foot lighter at 80°F than at 40°F. Reaching its maximum density at 39.2°F (4°C), water becomes lighter or less dense as it either cools or warms.

The density of water related to temperature induces a seasonal thermal stratification in many ponds and lakes. For a few weeks in the spring, water temperatures may be homogeneous from top to bottom in the standing water environment. Vertical water density is also homogeneous. During this time it is possible for the wind to mix the water in the lake or pond, distributing nutrients and flocculent bottom solids from the deeper waters to the surface. Dissolved oxygen is also mixed at this time and tests will indicate that water quality characteristics are very similar from the surface to the bottom.

As atmospheric temperatures increase with the coming of summer, the surface waters become warmer and as they warm they become lighter and rest over the cooler waters of greater density. Thus, a thermal stratification is formed for many months. In natural deep water, three layers of various temperatures and densities are formed. The upper layer, or epilimnion, represents the warm, more or less freely circulating waters of approximately uniform temperature. The epilimnion may vary in thickness from a few feet in shallow lakes to 40 or more feet in deeper lakes. Near the bottom of the lake a lower layer, or hypolimnion, represents the cold water region of uniform cold temperature. This may sometimes be referred to as the profundal region and represents a portion of the water body that is isolated from circulation with the upper waters and that receives no oxygen from the atmosphere during stratification. When the pond or lake environment is enriched with organic materials, the dissolved oxygen in the hypolimnion may be rapidly removed during periods of stratification, and its potential for supporting aquatic life becomes severely restricted.

The top and bottom water layers of approximately uniform temperatures are separated by a middle layer or thermocline. The thermocline is the region of rapid change in water temperature and is usually defined by a change of 1.8°F for each 3.28 feet variance in depth. The thermocline represents a vertical temperature transition zone with the upper region representing warmer water conditions and the lower region representing cooler water conditions.

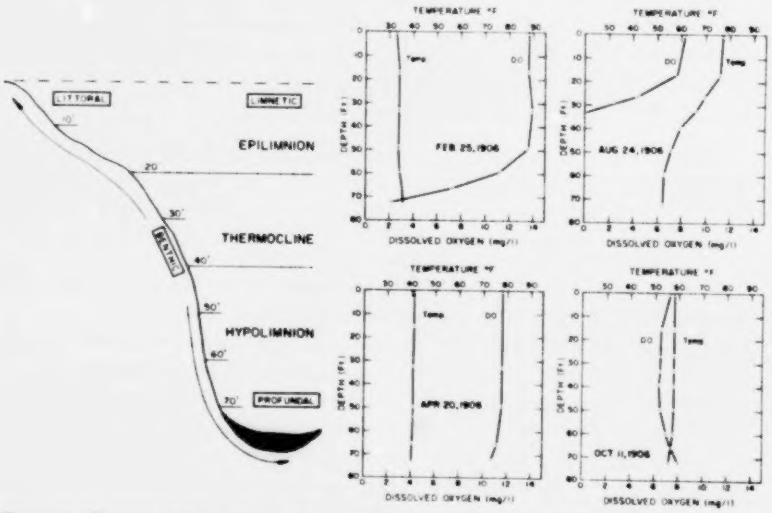

Figure 2. Diagram of lake zones with seasonal temperature and dissolved oxygen changes observed in Lake Mendota, Wisconsin (from Birge and Juday, 1911).

As atmospheric temperature cools and autumn approaches, the surface waters of a pond or lake cool also. The cooling process with the corresponding increase in water density increases the thickness of the epilimnion until the lake or pond becomes homothermous and again a period of complete water circulation, aided by the winds, begins. This phenomenon occurs from late September to December and depends upon the area and depth of the lake and its geographic location and local climatological conditions. The period lasts until changes in density re-establish stratification or until the lake is frozen over and a period of winter stratification follows.

Thus, the exchange of gases with those in the atmosphere are restricted during a greater part of the year for the entire lake environment. The water is saturated or nearly so with atmospheric gases in the spring and again in the fall. However, as soon as thermal stratification occurs, and lasting until the water again becomes homothermous, only the water of the epilimnion or upper portion has direct contact with the atmosphere.

Water warms more rapidly and to a higher degree in the shallow areas near shore. Microscopic life, both plant and animal, accelerates first in standing crop in these areas following the cooler temperatures of winter and, if the food-supplying nutrients are abundant, localized plant nuisances may develop that could spread to other sectors of the water body.

The temperature gradient in reservoirs may be more complex than that found in ponds or lakes. Main stream "run-of-the-river" reservoirs often have a small and fairly regular temperature gradient from top to bottom. In some situations, however, there may be a stream of inflowing cold water that tends to flow through the impoundment and be discharged by way of the penstock intake thus a thermocline is created below the water surface of the dam and extends upstream parallel to the bottom of the reservoir. A storage reservoir, often located at the headwaters of a stream, may have the characteristics of a lake because the water is often stored in the reservoir for a period of time extending for many months. Temperature gradients here are similar to those described for a lake. In addition, reservoirs frequently have density currents which are caused by differences in temperature, differences in the concentration of electrolytes, such as carbonates, and differences in silt content. These often extend from the inflowing area to the region of the penstock. In some instances, density currents have been detected from 60 to 80 feet below the surface. Density currents affect the fish populations since game fish orient themselves both to the stratum of stagnant water caused by density currents, as well as to the temperature range that suits them best. Often fish become trapped by a lack of oxygen within their chosen water.

Another physical factor of significant importance in the standing water environment is that of light. Rooted, suspended, and floating aquatic plants require light for photosynthesis and light penetration into water is exceedingly variable in different lakes.

The principal factors affecting the depths of light penetration in natural waters include suspended microscopic plants and animals, suspended mineral particles such as mineral silts, stains that impart a color, detergent foam, dense mats of floating and suspended debris or a combination of these. The region in which light intensity is adequate for photosynthesis in algae is often referred to as the trophogenic zone. This is a layer of water that encompasses 99 percent of the incident light reaching the surface. The depth of the trophogenic zone in ponds and lakes may vary from less than 5 to greater than 90 feet. The amount of incident light necessary for photosynthesis in vascular plants, as opposed to algae, is slightly greater for the former. Vascular plants can conduct photosynthesis when approximately 2.5 percent of the incident light remains in water.

In winter the presence of ice will limit light penetration, and when snow covers the surface of the ice the penetration is further reduced. It has been found that seven inches of very clear ice permitted 84 percent light transmission but only 22 percent of the light was transmitted through a similar thickness of cloudy ice. A 1-inch snow cover permitted only 7 percent light transmissions through the ice and snow and 2-inches of snow cover permitted only 1 percent light transmission. Without light the plants die and instead of producing dissolved oxygen through photosynthesis, oxygen is used through the process of decomposition and a fish mortality known as a winter kill may result in shallow water bodies when the oxygen is reduced substantially.

Oxygen enters the water by absorption directly from the atmosphere or by plant photosynthesis and is removed by respiration of organisms and by the process of decomposition. Oxygen derived from the atmosphere may be by direct diffusion or by surface water agitation by wind and waves. Conversely, wind and waves may also release dissolved oxygen under conditions of supersaturation.

In photosynthesis, aquatic plants utilize carbon dioxide and liberate dissolved and free gaseous oxygen at times of supersaturation. Since energy is required in the form of light, photosynthesis is limited to the photic zone where light is sufficient to facilitate this process. During respiration and decomposition, animals and plants consume dissolved oxygen and liberate carbon dioxide at all depths where they occur. Because excreted and secreted products in dead animals and plants sink, most of the decomposition takes place in the hypolimnion, thus, during lake stratification there is a gradual decrease of dissolved oxygen in this zone. After the dissolved oxygen is depleted, anaerobic decomposition continues with the evolution of methane and hydrogen sulfide gases.

Effects of Water Inflows and Discharges

The standing water environment receives its inflowing water from tributary streams, general land runoff, seepage from adjacent areas, and springs. The standing water basin is, thus, the first line receptacle for those materials that may be washed or drained from the lands within the drainage basin, for those substances that are discharged as waste water either without treatment or with some degree of treatment and removal, and for those materials that may enter the water environment from the atmosphere and other sources. Those materials that are discharged from the pond, lake, or other standing water bodies into downstream waterways eventually reach the estuaries or the oceanic environment, which become the ultimate receptacle for such materials.

An example of the cycling of an element by man would be that of phosphorus. Large deposits of phosphate rock are found near the western shore of central Florida, as well as in a number of other States. Deposits in Florida are found in the form of pebbles which vary in size from fine sand to about the size of a man's foot. These pebbles are embedded in a matrix of clay and sand. The phosphate rock beds lie within a few feet of the surface so that all of the mining is of the open pit type. Once the overburden is removed, the mining is carried out by using hydraulic water jets. Following this practice, the washing operation separates the phosphate from waste materials. The phosphate is then dried before marketing. Millions of tons of phosphate rock are mined each year in the United States. A recent report by the Council on Environmental Quality indicated that the phosphate rock mining operation disturbed 183,000 acres of the land in the United States. The process is similar to that of strip mining and the State of Florida experiences the greatest proportion of land destruction by this operation. Other States that have land destruction from phosphate mining operations include Idaho, Montana, North Carolina, South Carolina, Tennessee, Utah, Virginia, and Wyoming. There are a number of uses for the phosphate obtained from the mining operation and these include uses in fertilizers, as builders in detergents, and for other purposes.

The human body excretes about 1-pound of phosphorus as P per year. Other uses closely associated with man's activity, including the use of detergents, contribute about 2- to 2½-pounds per year per capita of phosphorus as P. Thus, about 3- to 3½-pounds per year per capita of phosphorus as P is discharged in waste water to municipal and private waste water treatment plants, and eventually to the receiving waterways. Conventional secondary sewage treatment with routine operating practices will remove only a small amount of the phosphorus in the waste waters. To remove additional amounts, it is necessary to adopt one of the advanced waste treatment methods that will precipitate the phosphorus from the waste waters in combination with other substances.

In the receiving waterways the phosphorus is used by algae and higher plants and may be stored in excess of use within the algal cell. Phosphorus is one of the contributors of nutrients that stimulates excessive development within the plant community and that gives rise to problems of eutrophication. The standing water body receives the phosphates and other nutrients from inflowing waterways and much is used in the biotic cycle of life. With subsequent decomposition of the plant cells, some phosphorus may be released immediately through bacterial action for recycling within the biotic community while another significant portion may be deposited with sediments. Much of the material that becomes combined with the consolidated sediments within the lake bottom is bound permanently and will not be recycled into the ecosystem. Studies on Lake Sebasticook, Maine, a Lake of 4,200 acres, indicated that the dry weight phosphorus (P) in the 0- to 1-inch stratum was 0.15 percent. Assuming that lake bed sediments contain 15 percent solids, the upper 1-inch stratum of Lake Sebasticook, just beneath the mud-water interface, might then contain about 200,000 pounds of phosphorus. The 1- to 2-inch stratum contained 0.09 percent phosphorus or about 120,000 pounds—some 80,000 pounds less phosphorus than the inch immediately above it. The 2- to 3-inch stratum contained 0.06 percent or about 80,000 pounds of phosphorus. Beneath the 1- to 2-inch stratum the phosphorus content ranged from 0.06 to 0.09 percent on a dry weight basis for each of the succeeding 1-inch strata.

The discharge from a lake or reservoir also has an effect on downstream water quality. Water flowing from a natural lake should be expected to be of a quality similar to that of the water in the uppermost stratum of the lake. However, when water in a free-flowing stream is impounded in a large storage reservoir, marked changes are produced in the physical, chemical, and mineral quality of the water. In reservoirs operated for flood control and power production, discharge releases are often reduced over weekends and other periods of off-peak power loads. Discharges likewise may be increased substantially during the week days. The penstock usually is located deep within the reservoir and the temperatures of the water discharged to the receiving stream may be substantially lower than the natural receiving water temperatures. Discharged water also may be low in dissolved oxygen concentration and release odors of hydrogen sulfide from decaying organic materials in the deeper portions of the reservoir.

The ecology of the receiving stream is drastically altered as a result of a low level discharge characterized by low temperatures and reduced dissolved oxygen concentrations. The warm water fish habitat may be destroyed. A cold water fish habitat may be created providing dissolved oxygen is sufficient. Bottom fauna may be changed in the receiving waterway from an assemblage of stoneflies and hellgrammites to an assortment of cold water species such as immature midges, black flies, caddisflies and scuds. Such a substantial alteration of the physical and chemical characteristics of the receiving stream can only produce a drastic change in the composition of the biota inhabiting the receiving water environment.

Biotic Considerations and Sample Station Selections

Organisms respond to the aquatic environment by producing an aquatic crop that is suited best for the particular environment in which they exist. Organisms respond also to changes that take place within their environment with shifts in species dominance in the aquatic community and sometimes with dramatic changes in the population numbers of a single species or a group of species with similar habitat requirements. Because of this response, and because the response may be less evenly distributed in the standing water environment as compared to the flowing water environment, the quality of water at selected sampling stations will be influenced to a great extent by the standing crop of organisms in the vicinity of that station. The consideration of this impact therefore becomes an important one in station site selection.

Algal population are influenced by climate. They tend to rise to the surface during hot humid days and disperse in greater depths during rain storms or turbulent water conditions. Several successive dark or cloudy days may be sufficient to kill a portion of a dense algal population and subsequent decomposition may bring about a localized dissolved oxygen reduction or a depletion and may result in fish kills from suffocation.

It is difficult to estimate the standing algal or plankton crop of a particular water body because of the diverse horizontal and vertical distribution of these organisms and their transportation by water movement. Early work on Lake Mendota, Wisconsin, indicated that on a dry weight basis the spring plankton crop was greatest and averaged 98 pounds per acre in winter compared to 360 pounds per acre in spring. The dry weight of an algal mass is approximately 10 percent of its wet weight. In Lake Sebasticook, Maine, the wet weight algal standing crop reached a maximum of 2,260 pounds per acre, which occurred on August 1. The filamentous alga, *Cladophora*, has been found to attain a population of 1 ton or more per acre.

The plankton that are developed in standing waters are not suited to life in flowing waters and usually die when they are discharged thereto. Conversely, river plankton are not adapted for the environment of standing water. Plankton are affected adversely by toxicants, turbidities, radical shifts in pH, temperature, currents, and acid mine discharges.

In early studies in Wisconsin on submersed aquatic plant populations, it was found that the 1- to 3-meter zone contained the greatest density of plants with lesser densities both shoreward and lakeward. The population density averaged about 7 tons wet weight and 1,800 pounds dry weight per acre. Other studies have indicated that various aquatic plant species have a substantially different population density; coontail populations have been found to approach 2,500 pounds per acre on a dry weight basis whereas sago pondweed was 1,700 pounds and duckweed 240 pounds per acre.

Bottom-associated organism populations vary quantitatively and qualitatively with the seasons of the year and from year-to-year in the same lake. The population is not distributed evenly over the floor in any lake but varies with depth and during the seasons. Investigators have found a zone of concentration of the organisms that shifts up and down the slope of the lake floor with seasonal changes.

Populations of bottom-associated organisms have been found to vary from 60 pounds per acre on a wet weight basis to 400 pounds per acre in the Mississippi River system where no aquatic vegetation was associated. Where submersed plants were present in the Mississippi River, population densities as great as 1,100 pounds per acre were found and one early study in New York indicated 3,500 pounds of such organisms in association with a *Chara* bed. Aquatic plants provide living space, food, and shelter for the invertebrates and the invertebrates in turn tend to select a particular aquatic plant with leaves that are finely branched and compact. Coontail and water milfoil rank extremely high as being the most productive harbor for fish food organisms because of their finely divided and very compact leaves.

Standing crops of fish have been found to vary from 75 pounds per acre on a wet weight basis to more than 1000 pounds per acre in the black-soil ponds in the flood plains of central Illinois. Additional information concerning standing crops and the amount of nutrients that may be combined in such crops is presented in Table 2.

To properly assess an eutrophication problem in the standing water environment, consideration should be given to all of those sources that may contribute nutrients to the watercourse. These sources could include sewage, sewage effluents, industrial wastes, land drainage, applied fertilizers, precipitation, urban runoff, soils, and nutrients

Table 2. Carbon, Nitrogen, and Phosphorus in Freshwater Environmental Constituents

Constituent	Standing Crop, lbs/ac		%C[1]	%N[1]	%P[1]	Ratio		Reference
	Wet	Dry				C:N	N:P	
Phytoplankton	1,000 to 3,600	100 to 360						Birge and Juday, 1922.
				6.8	0.69		10	Gerloff and Skoog, 1954.
			39	6.1	0.64	6.5	10	Mackenthun et al., 1968.
				9.0	0.52		17	Birge and Juday, 1922.
Attached Algae	2,000	200						Neil, 1958.
				2.8	0.14		2	Birge and Juday, 1922.
Vascular Plants	14,000	1,800		1.8	0.18		10	Rickett, 1922, 1924. Harper and Daniel, 1939.
Myriophyllum				3.2	0.52		6	Birge and Juday, 1922.
Vallisneria				1.8	0.23		8	Schuette and Alder, 1928, 1929.
Potamogeton				1.3	0.13		10	Schuette and Alder, 1928, 1929.
Castalia				2.8	0.27		10	Schuette and Alder, 1928, 1929.
Najas				1.9	0.30		6	Schuette and Alder, 1928, 1929.

Constituent	Standing Crop, lbs/ac		%C [1]	%N [1]	%P [1]	Ratio		Reference
	Wet	Dry				C:N	N:P	
Myriophyllum				3.0	0.5		6	Anderson et al., 1965.
Bottom Organisms								
Midges	200 to 400	40 to 80						Dineen, 1953; Moyle, 1940.
Chironomus				7.4	0.9		8	Borutsky, 1939.
Hyalella				7.4	1.2		6	Birge and Juday, 1922.
Hirudinea				11.1	0.8		14	Birge and Juday, 1922.
Sialis				8.1	0.6		14	Birge and Juday, 1922.
Fish	150 to 600							Swingle, 1950.
				[2] 2.5	[2] 0.2		10	Beard, 1926.
				2.8	0.18 to 0.49			Borgstrom, 1961.
					0.19			Love et al., 1959.
					0.20			McGauhey et al., 1963.
					0.29			Sylvester and Anderson, 1964.
Domestic Wastes [3]				2.6 to 3.3	0.18 to 0.24			Ingalls et al., 1950.
					5.1 to [4] 10.6			Engelbrecht and Morgan, 1959.
				[4] 45	[4] 8		6	McGauhey et al., 1963.
				20 to	5.3 to			

		[4]40	[4]10.6		4	Bush and Mulford, 1954.
		[4]61.3	[4]10.7		6	Oswald, 1960.
		18 to [4]28	3.5 to [4]9.0			Anon, 1967.
Sediments Lake Tahoe	0.6 to 19.8	0.6 to 1.6		4 to 25		McGauhey et al., 1963.
Wisconsin Lakes	4.4 to 40.5	0.6 to 3.6	0.12 to 0.6	8 to 14	5 to 6	Black, 1929; Juday et al., 1941.
Madison, Wis. Lakes		0.7 to 0.9	0.1 to 0.12		6 to 9	Sawyer et al., 1945.
Green Lake		0.6	0.17		4	Sylvester and Anderson, 1964.
Lake Sebasticook	10 to 34	0.3 to 1.8	.06 to .16	8 to 44	5 to 16	Mackenthun et al., 1968.
Klamath Lake	8.6	1.2		7		Thomas, N. A., Unpublished.[6]
Boston Harbor	2.3 to 5.0	.06 to .41				Stewart, R. K., 1968.[5]
Organic River Sediments	0.03	0.0027			12	Finger and Wastler, 1969.
Pulp & Paper Wastes in River	5.3	0.23		22		Finger and Wastler, 1969.
Untreated Domestic Wastes	3.54	0.3		12		Finger and Wastler, 1969.

Constituent	Standing Crop, lbs/ac		%C[1]	%N[1]	%P[1]	Ratio		Reference
	Wet	Dry				C:N	N:P	
Untreated Chemical and fertilizers and domestic wastes			3.15	0.12		26		Finger and Wastler, 1969.
No tributary wastes			0.55	0.05		11		Finger and Wastler, 1969.
Sand; silt; clay; loam			0.4 to 2.1	.02 to .10		20		Ballinger and McKee," 1971.
Stable sludge; peat; organic debris			2.0 to 5.0	.10 to .20		20 to 25		Ballinger and McKee, 1971.
Paper mill wastes			6 to 15	.10 to .30		50 to 60		Ballinger and McKee, 1971.
Packinghouse Wastes			2.8 to 4.3	.30 to .50		8 to 10		Ballinger and McKee, 1971.
Fresh sludge; decaying algae; sewage solids			5 to 40	.70 to 5.0		7 to 8		Ballinger and McKee, 1971.

Log Pond Bark	50.6	.5	.02	100	25	Thomas, N. A. Unpublished.[6]
Sewage sludge in river	5.8	0.28	.18	21	2	Thomas, N. A. Unpublished.[6]
Algae; sawdust;						
sewage	14.6	0.93	.11	16	9	Thomas, N. A. Unpublished.[6]
Leaf litter	28.3	1.63	0.11	17	15	Warner, R. W. et al., 1969.[7]
Sand	0.2	.02	.005	10	4	Warner, R. W. et al., 1969.[7]
Loam	2.7	.19	.02	14	10	Warner, R. W. et al., 1969.[7]
Muck	7.3	.52	.04	14	13	Warner, R. W. et al., 1969.[7]
Floating Waste Wool	37 to 43	3.4 to 4.7	.08 to .09	9 to 11	38 to 58	[8].

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[1] As the total element in percentage of the dry weight, unless specified otherwise.

[2] Calculated on wet weight.

[3] Average sewage flow can be calculated at 100 gallons per capita per day.

[4] mg/1.

[5] Biological Aspects of Water Quality, Charles River and Boston Harbor, Massachusetts by R. K. Stewart. Technical Advisory and Investigations Branch, Cincinnati, Ohio (1968).

[6] Technical Advisory and Investigations Branch, Cincinnai, Ohio.

[7] Analyses of soil types from "Black-Water Impoundment Investigations," by R. W. Warner, R. K. Ballentine and L. E. Keup, Technical Advisory and Investigations Branch, U.S. Department of the Interior, Cincinnati, Ohio (1969).

[8] Fertilization and Algae in Lake Sebasticook, Maine. Department of Health, Education, and Welfare, Technical Advisory and Investigations Activities, Cincinnati, Ohio (1966).

released from bottom sediments and from decomposing plants. Transient waterfowl, fallen tree leaves, and ground water may contribute important additions to the nutrient budget. Flow measurements are paramount in a study to quantitatively assess the respective amounts contributed by those various sources during different seasons and at different flow characteristics. In a receiving lake or pond, an estimate of the quantity of nutrients contained by the standing crop of algae, aquatic vascular plants, fish, and other aquatic organisms are important considerations. A knowledge of those nutrients that are harvested annually through the fish catch or that may be removed from the system through the emergence of adult insects will contribute additional information to an understanding of the nutrient budget.

The interaction of specific chemical components in water, prescribed fertilizer application rates to land and to water, minimal nutrient values required for algal blooms, vitamins required, other limiting factors, and the intercellular nitrogen and phosphorus concentrations of plants are likewise important. Usually it is necessary to determine that portion of the nutrient input attributable to man-made or man-induced pollution that may be controlled as opposed to that input that is natural in origin and therefore usually not controllable or controllable only to a minor extent. A nutrient budget should define the annual nutrient input to a system, the annual outflow and that which is retained to recycle with the biomass or become combined with the solidified bottom sediments.

Sediments are best collected with a device that permits a core of the material to be extracted from which identifiable segments may be selected for examination. These segments may be examined for pollen, diatom skeletons or chitinized remains of cladocerans or midges, as well as selected chemical constituents. Generally carbon and nitrogen and often phosphorus are determined. The carbon, nitrogen, and phosphorus contents and their respective ratios are important values to aid in the identification of the sediment, and to calculate the amount of major nutrients contained within a portion of the biomass or a stratum of sediment. From this information it should be possible to judge the relative return of nutrients to the water mass when the particular ecosystem component undergoes decomposition, or any change that fosters nutrient release.

A lake or reservoir usually retains a portion of those nutrients that it receives from its various sources in its consolidated sediments. The amount or percentage of the nutrients that may be retained is variable and will depend upon: (1) the nutrient loading to the lake or reservoir, (2) the volume of the euphotic zone, (3) the extent of biological activity, (4) the detention time within the basin or a time allotted for biological activity, and (5) the level of the penstock or the level of discharge from the lake.

Physical Considerations and Sample Station Selection

Preparatory to the investigation of a pond, lake, or reservoir, an accurate map of the drainage basin should be obtained. Such a map will give an indication of the area of land that potentially could contribute to water quality within the lake. Potential sources of pollution should be indicated on such a map because a determination must be made of the extent of influence to the lake or standing water environment from those sources that both contribute directly and indirectly to its conditions. In the determination of remedial measures to correct the standing water problem, consideration must be given to all potential contributing factors to that problem.

Whenever possible a contour map of the pond or lake basin will be of tremendous advantage to the investigators. When such a contour map is not available one should be constructed for the waterway in question because the location of sampling stations and the types of samples to be collected in a standing water body depend in large extent on the contour of the basin. A contour map provides also for the calculation of the volume of water within a particular depth stratum and this is important in ascertaining the volume that may be representative of a particular set of conditions found through sampling.

Identification of pollution sources within the drainage basin includes a determination of the characteristics and volumes of waste water discharges from municipalities and industries. If a thorough investigation of the waste water components cannot be accomplished within the constraints of the study plan, the type of industry and its manufactured products along with the number of persons connected to the municipal sewerage system would be useful information in interpreting the data collected from the field investigation. Pertinent data on both municipal and industrial wastes discharges to a particular drainage basin should be in the files of the State water pollution control agency.

Additional physical information that will serve as essential background material for a lake investigation includes the following: Area, mean depth, maximum depth, area of depth zones, volume of depth strata, shore length, shore development, littoral slope, number of islands, area of islands, shore length of the islands, drainage area, rate of runoff, average inflow to receiving pond or lake, average outflow, detention time within the pond or lake, water level and water level fluctuations.

Sample Station Selection

The establishment of stations within the flowing water environment was discussed in the previous chapter. Sampling stations should be located on major tributaries to a standing water basin in similar manner. As a minimum, it is imperative that a sampling station be located near the mouth of each tributary to the standing water basin and that a station be located near the pond's or lake's outfall. The effluent from a natural lake will usually give a better than average composite of the surface waters of the lake. The discharge from a reservoir penstock located below the thermocline, however, will not give a representative sample of the productive zone of the reservoir but instead will show water quality in a portion of the hypolimnion. Additional stations downstream within the receiving water environment would indicate the effects of such a low level discharge on the receiving waters.

Within the lake, pond or reservoir a number of sampling sites may be chosen depending upon the problem under investigation and the conditions to be studied. An investigation of the kinds and relative abundance of aquatic vegetation would naturally be limited to the littoral area. A mapping of aquatic plants with an indication of predominant species and their relative abundance often proves useful for future comparisons to record relative changes in the vascular plant population. A mapping of the deep water attached plants such as *Chara* may be accomplished with the use of one of the sampling dredges. Mapping of the vegetation generally can be accomplished satisfactorily with a boat reconnaissance survey, and frequent inspection stops, in the littoral area of a standing water basin during the peak of the summer vegetative growing season.

Fish sampling also is often more profitable in shallow water areas. Such sampling can be accomplished with the use of electro-fishing devices, seines, hoop nets, or gill nets set in the region of the thermocline. The latter will sample a fish population not usually observed in shallow-water areas.

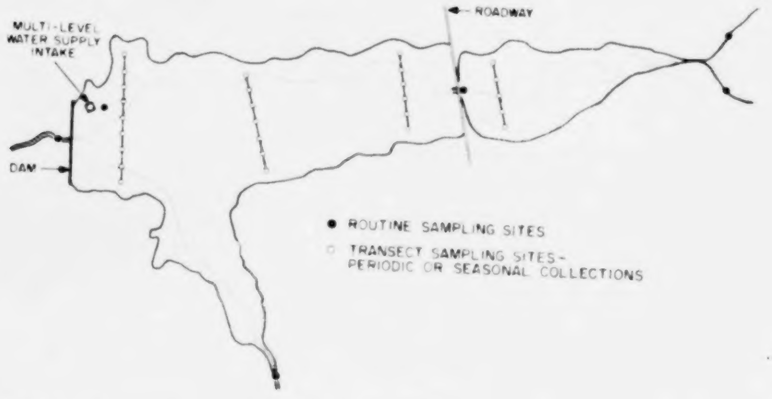

MULTI-LEVEL WATER SUPPLY INTAKE
ROADWAY
DAM
● ROUTINE SAMPLING SITES
○ TRANSECT SAMPLING SITES– PERIODIC OR SEASONAL COLLECTIONS

Figure 3. Diagram of a long, narrow reservoir showing suggested sampling stations.

The use of transections in sampling a lake bottom is of particular value because there are changes in depth and because benthos concentration zones usually occur. Unless sampling is done systematically and at relatively close intervals along transections, especially those that extend across the zone between the weed bed and the upper extent of the hypolimnion, concentration zones may be missed entirely or represented inadequately. Maximal benthic productivity may occur in the profundal region. Because depth is an important factor in the distribution of bottom organisms, productivity is often compared on the basis of samples collected from similar depth zones. Collections along a transection will sample all depth zones, but a sufficient number of samples must be taken to make the data meaningful.

A circular lake basin should be sampled from several transections extending from shore to the deepest point in the basin. A long narrow basin is suitable for regularly spaced parallel transects that cross the basin perpendicular to the shore beginning near the inlet and ending near the outlet. A large bay should be bisected by transections originating near shore and extending into the lake proper.

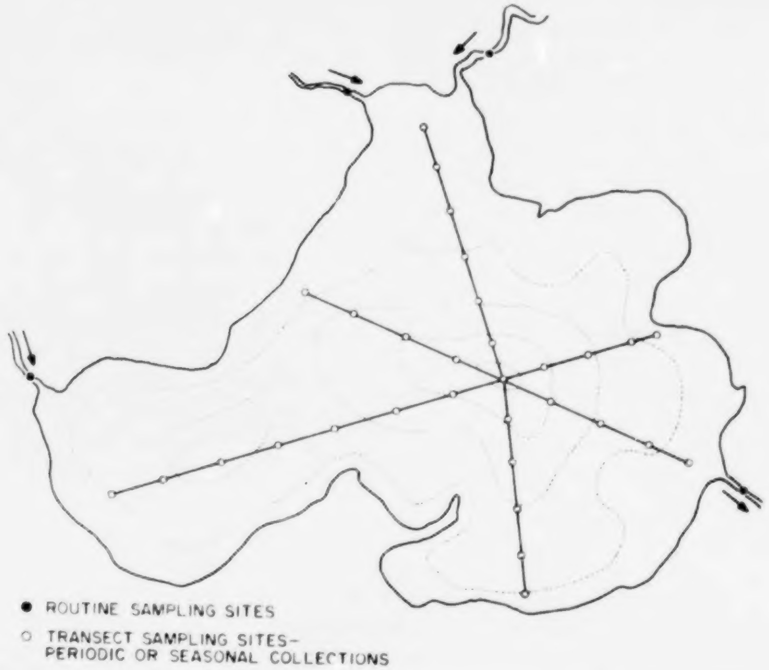


Figure 4. **Diagram of a natural lake basin showing suggested sampling sites. Samples taken from points on transaction lines on a periodic or seasonal basis are valuable to determine vertical water characteristics and the benthic standing crop.**

Transections aid also in sampling the plankton population. Because of the number of analyses necessary to appraise the plankton population, however, more strategic points are usually sampled such as water intakes, a site near the dam in the forebay area or discharge, constrictions within the water body, and major bays that may influence the main basin. Because of significant population variations, plankton samples must be taken vertically at periodic depths and at different times over the 24-hour day.

It often is impractical to make vertical determinations of plankton and various chemical constituents at each of the stations located on the transection lines that were selected for an examination of bottom-associated organisms. Availability of resources dictates the number of stations that can be selected for a vertical determination of various water quality constituents. Certainly one such station for vertical analyses should be located in the deepest portion of the lake or pond basin. Other stations should be selected so that the data derived therefrom are representative insofar as possible of that portion of the standing water basin that is represented by the particular station in question. In studies of Lake Sebasticook, Maine, for example, five stations were selected within the Lake basin for vertical sampling. A number of additional flowing water stations were selected to depict conditions in inflowing streams.

As a minimum, vertical temperature and dissolved oxygen profiles should be obtained during each period of study. The number of vertical samples for other water quality constituents will depend upon the problem being investigated and available resources for sample analyses. As a minimum, two sampling points should be located in the epilimnion, at least one in the thermocline and an additional two to represent the hypolimnetic waters.

Vertical samples should be taken from the pond environment also because stratification does occur even in shallow ponds. Again, the number of sampling points within a vertical column will be governed in large measure by the type of problem under investigation. It should be possible to substantially reduce the number of points to one representative of the near surface waters, one of the mid-depth waters, and one of the near bottom waters.

There are definite advantages in sampling the benthic population in winter beneath the ice cover in lakes. Samples can be collected at definite space intervals on a transection and the exact location of sampling points can be determined. Collections at this time are also at the peak of the benthic population when emergence of adult insects does not occur.

Reservoirs usually are long and narrow water bodies with the widest portions occurring downstream near the dam. They are particularly suitable for the placement of imaginary transection lines that extend perpendicularly from one shore to the opposite shore. Sampling stations can be conveniently located on these transections. In addition, water use return waters or areas designated for water use removal should be sampled.

Sampling Frequency

The frequency of sampling a standing water environment depends upon the objectives of the study. When possible, samples should be collected during each season to depict seasonal changes in chemical substances and biologic populations. A sampling time corresponding to the spring or fall overturn is often helpful. A sufficient number of samples should be collected from each sampling point on different dates during each of the survey periods to permit comparison of data among different water strata and different seasons. A minimum of five daily samples should be collected from each point, but for some purposes this number should be increased.

Vascular aquatic plants may need to be surveyed only during their active growing period when the population is at a peak. The sampling for benthos should coincide with the fall or winter season as a minimum and preferably samples should be taken during each of the seasons. Significant chemical constituents and samples for algal populations should be taken during each of the sampling periods.

In the pond environment, sampling might be continued on a monthly basis to depict fluctuations throughout the year. Consideration should be given to the collection of some samples during the early morning hours to determine if a significant fluctuation in dissolved oxygen concentration occurs because of respiration of the standing crop of aquatic vegetation during periods of no sunlight. Dissolved oxygen may fluctuate from as high as 30 milligrams per liter to 0 during a 24-hour period in extreme situations.

10

Special Studies

SPECIAL investigations or studies involve a combination of a scientific investigation with an inquisitiveness and perceptivity of a Sherlock Holmes. Such investigations usually have as a singular objective to identify the cause of a problem and to recommend control measures. Because environmental problems vary tremendously in complexity, special investigations likewise vary in the amount of manpower and monetary resources, as well as time allocation necessary for study completion. Special investigations may be grouped into those that address themselves to particular and singular problems, investigations of more complex problems and catastrophes, and studies to increase the fund of knowledge about interactions in the aquatic environment or to serve as class training projects.

Particular and Singular Problems

The investigation of particular and singular problems usually is not time consuming and resource demanding but may require an on-site appraisal and laboratory examination. Such problems include the determination of the cause of red, white, or green water; determination of the source of animal hairs or other visible objects in private water supplies; identification of a pond scum or a type of aquatic weed that may be causing a problem; or the identification of any problem organism.

The background and experience of the investigator contributes in large measure to the success of this type of aquatic detection. Often a cursory examination of a sample is adequate to diagnose a problem organism and sometimes to formulate corrective recommendations. Red water for example can be caused by one of several species of iron bacteria, an alga, *Oscillatoria rubescens*, a flagellate, *Euglena sanguinea*, and, under certain conditions, a dense population of sludgeworms or bloodworms may give the appearance of red paint on the bottom of the waterway.

The microscopy of water is fascinating and entertaining, particularly in the identification of "unknown" organisms. Appropriate, easily obtained references are adequate for the gross identification of most plants and animals. The identification of paper-making and other fibers that are often associated with industrial waste waters requires special references and the reader is referred to Anon., 1953, and Carpenter et al., 1963. Mammalian hair identification guides (Brown, 1942; Mathiak, 1938) are useful in identifying the type of animal that may have drowned in a local well that probably had an improper cover.

The investigation of more complex aquatic problems and catastrophes may require a study plan, field crew, and laboratory support. Examples of such studies would include the investigation of fish kills, the determination of animal or plant interferences of domestic or industrial water supplies, and the determination of the causes or extent of pond or lake eutrophication.

Fish Kills

Fish mortalities are a visible sign and later an odoriferous indication of an abnormal event within the aquatic environment. Fish mortalities result from a variety of causes, some of natural origin and some man-induced. Those from natural causes may result from such phenomena as acute temperature changes, storms, ice and snow cover, decomposition of natural organic materials, salinity changes, spawning mortalities, and bacterial or parasitic epidemics. Man-induced fish kills may be attributed to municipal or industrial wastes, agricultural activities, and other activities by man such as water manipulation that significantly alter the quality of the aquatic environment.

The Environmental Protection Agency has published an annual report on fish kills caused by pollution since 1961. The latest publication for the year 1970 states that about 23 million fish were reported killed by water pollution in 634 separate incidences in 45 States. The 1970 report showed a 36 percent increase in reports by States compared to 1969. Probably this can be related to increased cooperation from the State reporting officials, improved reporting practices, and increased public awareness of pollution-caused fish kills. There were 31 reported kills where the number of dead fish equaled or exceeded 100,000 and 5 of the reported kills indicated dead fish in excess of 1 million.

In 1970, industrial operations were responsible for approximately 9.6 million fish killed based on 177 reports. Operations associated with municipalities reportedly killed 6.6 million fish in 1970 based on 109 separate reports. Other operations including pollutants from highway and building construction, airport and service station operations, and mosquito control were charged with 3.8 million dead fish based on 153 reports, and agricultural operations killed approximately 1.8 million fish based on 95 reports.

As in past years, the greatest number of fish kills occurred during the summer months when warm water and low stream flows from May through September enhanced the effects of pollutional materials. Almost 80 percent of the fish reported killed in 1970 were killed between May and September with July indicated as the month with the greatest number of reports. Of the 633 fish kills reported in 1970, 487 were killed in rivers with a loss of over 13 million fish involving 1,865 stream miles. Fish kills occurred in 33,000 acres of lake water with over 3 million fish killed in 111 incidents. Coastal areas were responsible for 36 kills involving more than 6 million fish along 12,000 miles of shoreline. Fish die also of old age but the numbers so affected at any one time are usually small and would not be expected to incite public attention.

In the initial phases of investigating fish kills, speed is all important. Dead fish disintegrate rapidly in hot weather and the cause of death may disappear or become unidentifiable within minutes. Early arrival at the scene after a fish kill begins usually determines the success of the investigator's evaluation of the problem. The initial investigation can be greatly expedited through the cooperation of persons who report immediately the time and place of observed kills, the general kinds of organisms affected, an estimate of the total number of dead fish, and any unusual observed phenomena.

Because the presence of dead fish is a dramatic indicator of an environmental catastrophe, a knowledge of the cause of the mortality is of importance to the users of the water. Training in the observation and investigation of environmental catastrophes such as fish kills should begin early in the life of a student interested in the life sciences and should be well developed at the high school level.

Preparation for the investigation of a fish mortality is similar to the preparation for any other investigation of a waterway reach except that the preparation should be accomplished in anticipation of the investigation rather than at its initiation to ensure speed of response. Maps should be consulted and the location of the reported mortality along with the location of known sources of contributing pollution should be noted. Often a knowledge of a history of fish mortalities in the area will contribute valuable information. The laboratory analyst should be alerted to expect samples from the investigation. The basic type of equipment that most likely would be employed would be a thermometer, dissolved oxygen, pH, and conductivity testing equipment, a general chemistry kit, dip net, dredge or square-foot bottom sampler for sampling benthos, appropriate standard sieves, buckets, waders, a long-handled garden rake, sample containers, preservative, an ice chest, and a boat.

The time that the fish kill began and when it ended should be carefully determined from local observers, or by the investigator. The fish kill area should be defined by reference to legal descriptions of adjacent lands or political subdivisions. In streams, and often in lakes, fish are washed or blown rapidly away from the specific kill location. In streams also the cause of the kill may be carried downstream with the current as a "slug" along with floating dead fish. The number of fish killed should be estimated as accurately as possible, as well as the kinds of fish involved. For large lakes and rivers, a measured distance of shoreline may be traversed by boat and the number and kinds of dead or dying fish counted. Estimates can be made by projecting representative counts to the area of total kill. For smaller streams the banks may be walked and counts made on the observed numbers of dead fish by species. An appraisal should be made of the size range of each species killed and observations should be made on the predominance of the particular size groups, when distribution appears to be other than random. Other killed wildlife or animals including invertebrates should be observed in a similar fashion.

The fish kill investigation should be conducted in such a manner that evidence from it can be introduced into court. The names of witnesses to the kill, together with a detailed report of their observations and a signed statement should be obtained, when possible. Samples collected in the field and transported to a central laboratory for examination should be sealed and so identified by the sender that the chain of evidence remains intact. Each sample as received in the laboratory should be logged in and thereafter the date and exact time for each step in the analytical procedure should be recorded by the responsible technician. The log should be continuous and account for all the time that the sample is in the laboratory until the analyses are completed. When not in use such samples should be stored in a locked room.

A number of physical, chemical, and biological observations are necessary to define the cause of death, in the "typical" fish mortality. Precise instructions to conduct such observations can be obtained from the State water pollution control agency. In addition, the Environmental Protection Agency in 1970 published a brochure entitled, "Investigating Fish Mortalities," that detailed some of the indicated tests and observations to be undertaken.

Water temperature fluctuation is a possible direct or contributing cause to fish mortalities. Temperatures should be recorded during the hottest part of the day. Stream flows should be observed and it should be noted whether they are reasonably constant or intermittent. The weather conditions prevailing at the time of the kill may be an important factor especially if weather was extreme. Other noteworthy observations include the appearance of any unusual physical characteristics of the water, the presence of oil or of excessive biotic growths of any kind, the color and appearance of rocks or debris, and the physical actions of the fish in a moribund state. Photographs should be obtained where possible to record the physical conditions observed.

Certain chemical and biological data should be collected at various stations throughout the kill areas, as well as in upstream and downstream unaffected areas. Locating these sampling stations is a matter principally for the judgment of an experienced observer but they should be so located that the extent of water quality affected can be defined and the maximal alteration in water quality can be delineated. The dissolved oxygen should be determined, as well as the specific conductance, pH, methyl orange alkalinity and other pertinent water quality characteristics. Water samples for chemical analysis should be collected in chemically cleaned bottles and analyzed for suspected toxic substances. A 1-liter sample volume is minimal and 10 such samples from the kill area may prove valuable.

To preserve water, mud, and biologic samples for pesticides analysis, the freezing of all wet sample is recommended. When freezing cannot be done, thoroughly cleaned glass containers must be used and these should have a screw-type cap lined with teflon. Water proof tags should be attached to all samples stating the place, date, and time of collection, type of sample, condition of the specimen when collected, and the name of the sample collector. Silt or sludge samples varying from 1-quart to 1-gallon size are collected preferably in quart glass jars. Dry samples require no preservation, nor do wet silt or sludge samples when they are dried rapidly. When rapid drying is not possible, samples may be preserved with 10 percent formalin and the preservation method should be indicated on the label. In all surveys of this nature it is imperative that arrangements have been made with the appropriate laboratory to receive samples for analyses.

Samples of moribund or recently dead fish and in some cases other organisms should be collected, placed separately in plastic bags, labeled, quick frozen immediately with dry ice, and shipped frozen to the laboratory. Ten fish of a given species and size affected should be obtained in this manner. When possible such fish should average 1-pound each. A similar poundage and number of live specimens of the affected species should be obtained from outside the kill area but within the same water body to serve as control specimens. The preservation and shipment of control specimens should be identical to that of specimens obtained within a kill area.

Fish should also be preserved for histological examination and preservation may be with 10 percent formalin. The fixing fluid volume should be approximately 10 times the bulk of the fish tissue, and internal tissues should be exposed by an abdominal incision to permit the fixative to penetrate the flesh. When disease is suspected, five moribund fish of each involved species should be placed on wet ice and delivered to a fish disease laboratory within 24 hours to ensure satisfactory specimens for the detection of fish diseases.

Accurate recording of symptoms when collecting specimens is of great importance in diagnosing the positive agent or agents. Conditions such as general appearance, sight of hemorrhage, body color, and organ color must be recorded immediately upon capture. For certain analytical tests, such as the determination of pesticidal levels, blood samples should be collected from dying or recently dead fish. This procedure involves drying the exterior of the fish with paper towels, wrapping a paper towel around the fish in the anal region and cutting off the caudal peduncle (tail) with sharp scissors. The fish is held in the vertical position, tail down, with the blood dropping in a 10 to 15 cc vial until 5 cc of blood is collected. If blood clotting reduces the flow, a second shearing may again free the flow. Composite samples from several fish of the same species may be necessary to obtain 5 cc of blood. Five vials containing 5 cc each of blood for each important species are preferred. The vial stopper or cap is covered with aluminum foil; it is closed and the sample is frozen immediately and handled with care so that the sample does not touch the foil. A code number is given to the blood sample so that it can be matched with the carcass, which is retained and frozen separately in a plastic bag.

It is important to make collections of algae when they are present in a quantity sufficient to be a potential factor in the kill. Careful observations on the extent and density of rooted aquatic plants also should be made. In collecting attached or planktonic algae for pesticidal analyses, collect 10 cc of concentrated material in a 20 cc glass vial. Attach tag giving basic collection identification and indicate volume of water from which the sample was collected and the method of sample concentration. In dense algal mats, such concentration can be effected with the use of a sieve. Cover the top of vial with aluminum foil, cap and ship frozen. Dilute fresh algal cells or an algal suspension in the affected water may be injected into laboratory mice to determine algal toxicity. Such samples should be returned rapidly to the laboratory in a fresh and chilled state for such tests.

Following these more urgent aspects of the fish kill investigation, sampling of benthic organisms in the accepted manner for biologic investigation of water pollution will aid in defining the extent and cause of the fish kill.

Lastly, the field observations and the laboratory analyses should be confined into a succinct report that will withstand critical cross-examination. All field notes, laboratory notes, and data forms must be maintained until there is assurance that they will not be needed further in subsequent court or other actions.

A sample collection summary for a fish mortality investigation would include:

1. Ten 1-liter water samples from kill area from chemical analyses. Other 1-liter samples from control and other stations.
2. Ten pounds including 10 individuals of dying fish of each important species frozen with dry ice and an equivalent amount and number of control fish.
3. Five small fish of each important species preserved in formalin.
4. Five dying fish of each significant species placed on wet ice and delivered to fish disease laboratory within 24 hours.
5. Five vials containing 5 cc each of blood from each important fish species.
6. One quart to 1-gallon of sludge or sediment.
7. Ten cc of concentrated algae, frozen.
8. Ten cc of concentrated algae, chilled.
9. Benthos samples.

Water Supplies

Water supplies are derived either from the subsurface or from surface storage reservoirs or lakes and streams and each may have its associated chemical or biological problems. Algae, protozoa and diatoms can produce tastes and odors and clog filters. Iron bacteria produce nauseous tastes and odors and clog pipes. Copepods may infest a system when eggs pass through filters, and small nematode worms, sowbugs, and midge larva or bloodworms have been found in distribution systems.

Before a source for a water supply is finally selected, it should be surveyed by a competent aquatic biologist to evaluate present and probable future conditions that might affect the water quality. Often through an analysis of the chemistry of the inflowing water, an evaluation of the proposed reservoir morphology and an assessment of soils to be inundated, a prediction can be made regarding future problems likely to result when subsequent construction and reservoir filling are completed. The elimination of undesirable shallow areas can often be accomplished more cheaply during construction than with continual surveillance and maintenance of acceptable water quality in these areas after reservoir filling.

Impounded water may result in the leaching of undesirable materials from inundated soils. When present in excessive concentrations, such materials can interfere with the desired water uses. For example, color may become objectionable aesthetically. Excessive iron in water supplies stains laundry, produces a disagreeable taste, interferes with filtration, and supports iron bacterial growths. Iron is more soluble in water when oxygen is absent, when organic materials are present, and when the water is acidic. Manganese should be absent from finished water and, when present in excess, stains laundry and produces tastes. Manganese is affected in its solubility similarly to that of iron. Phosphorus concentrations in excess of 0.1 mg/l may interfere with coagulation in water treatment plants and in excess of 0.05 mg/l may stimulate the excessive growth of algae and other aquatic plants. Algal growths impart undesirable tastes and odors to water, interfere with water treatment, become aesthetically unpleasing, and alter the chemistry of the water supply. Likewise, nitrogen is an important factor in water supplies. The decomposition of organic materials produces ammonia that, in an environment without abundant oxygen, may not oxidize to nitrate. Ammonia reacts with chlorine to form chloramines, which interfere with disinfection. In addition, nitrogen is a nutrient that, with phosphorus, supports excessive aquatic vegetation. The possibility of the development of such problems in a new reservoir can often be predicted through a chemical analyses of the inflowing water, as well as the soils to be inundated and an experiment to determine the probability of leaching of materials from the soils to superimposed water.

To prevent water quality degradation in newly formed reservoirs, it may be necessary to remove woody debris prior to flooding, particularly rotting logs and stumps. If tests show that organic soils could have a marked effect on a significant area of the reservoir, these soils should be excavated or covered with at least 2 feet of mineral soil, which is effective in preventing adverse effects on the overlying water. As the reservoir ages the effects of the original soil will diminish because of a decrease in the rate of decay and the extraction of available solutes. Clays and other soils washed in with spring freshets gradually will cover the original soils.

When new reservoir areas are flooded, the terrestrial vegetation is killed including the shrubs and remaining trees. Subsequent decomposition and leaching from the topsoils release nutrients and may contribute to the release of iron and manganese, as well as increase the background color. The nutrient release in turn provides a food source for algae and other microscopic organisms that contributes to water quality degradation. It has been found to take from 10 to 15 years to reach a state of stabilization following the inundation of vegetation and rich topsoils. Stripping of the top soil and removal from the reservoir site or burial along with the removal of shrubs, brush, and logs may be necessary to prevent the formation of taste and odors and other undesirable qualities associated with new reservoirs.

Algae are considered to be the most important causes of tastes and odors in water supplies. Particular organoleptic sensations have been associated with a large number of algal genera. Their decay and decomposition in association with fungi and bacteria accentuate their taste and odor producing properties. The number of algal cells present per unit of water for a particular algal genus is a probable indication of its potential for the production of organoleptic sensations in water supplies. Early control of an algal population through the use of an algicide in a reservoir or enclosed basin often alleviates the potential problem but the control measures usually have to be repeated on more than one occasion throughout the course of the warm summer months.

Algae are also a primary cause of filter clogging in water treatment operations. Efficient coagulation and sedimentation may remove 90 to 95 percent of the algae from the water, however, the algae remaining may still be sufficient to cause gradual or even rapid loss of head in a sand filter. The clogged filter must then be backwashed and frequent backwashing is an expensive undertaking in water treatment because the filter being backwashed is removed from service and a certain amount of water is wasted during the backwashing procedure. Filter runs may often extend from 30 to 100 hours before backwashing is required or may be shortened to 3 to 10 hours when algae are present and interfere with the filtering operation. Diatoms are especially noteworthy as filter clogging organisms. The additional cost of operating a water treatment plant imposed by the problems of algae as a filter clogging organism may extend into the hundreds of thousands of dollars per season in a large water treatment plant.

Algae sometimes contribute to corrosion either directly in localized places where they may be growing or through their modification of the water by physical or chemical changes. Green- and blue-green algae, growing on the surface of submersed concrete, have caused the concrete to become pitted and friable. The algae have been reported also to cause corrosion in metal tanks and basins open to sunlight. *Oscillatoria* growing in abundance in an open steel tank has caused serious pitting of the metal. The algal growth permitted the pitting to take place by releasing oxygen which combined with the protective film of oxide over the steel. When the steel tank was covered to prevent the entrance of light, the algae disappeared and corrosion stopped. Growths of algae increase organic deposition in pipes and increase the dissolved oxygen in the water during daylight hours through photosynthesis. Their growth also produces changes in pH and carbon dioxide content all of which may affect the rate of corrosion.

Growths of iron bacteria can be found in deep wells and frequently occur in water distribution systems. These bacteria may cause turbidity and discoloration of the water and be responsible for some of the unpleasant tastes and odors that are produced either directly or indirectly as the dead bacterial cells are decomposed by other microorganisms. When present in great numbers, as they are sometimes associated with the distribution system near fire hydrants, the bacteria impart a reddish coloration to the water and increase the turbidity substantially. These organisms also may be identified by a microscopic examination of a small sample of water. When present in few numbers, it may be necessary to pass a sample of water through a membrane filter where subsequent microscopic examination should reveal iron bacteria in abundance if they are present. Leuschow and Mackenthun (1962) describe such a technique for the detection and enumeration of iron bacteria from a water supply faucet.

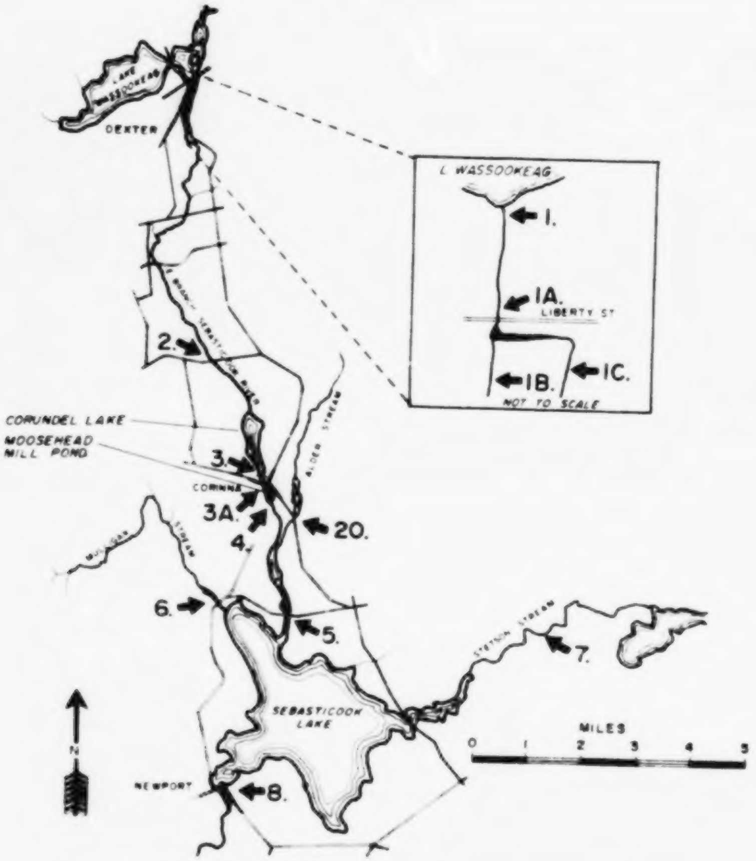
Published records have indicated that certain animals can pose problems as unwanted inhabitants of water supply systems. Examples of such animals include bloodworms that have been found in certain distribution systems. Bloodworms have been a nuisance organism in the sand filtration process because they live upon the organic material collected by the filters and construct tubes in which they live within the filter media. When the insects emerge as adults the empty tubes on occasions have been found to allow the water to pass through the filters in an unfiltered state. Other types of worms and nematodes also have been found in distribution systems. Copepods or water fleas have been a problem on occasions and the eggs have been found to pass through filters, later hatching into mature forms in the potable supplies. Sponges have been a problem in pipes because of their ability to line portions of the pipe with a rough coating that hinders the flow of water or, when heavy infestations occur, stop the flow of water. Clams and snails have been reported from distribution systems and have been a problem because of incrustations in intake pipes.

As a school project, and when a membrane filtering apparatus is available in the laboratory, samples of water from a laboratory faucet may be examined microscopically from time to time for any materials it contains. A very informative field trip would be a visit to the local municipal water supply where the operator undoubtedly would be pleased to explain the process of water purification. When the supply is from a surface source, such as a reservoir, samples collected from the reservoir and from various points throughout the water purification system for microscopic investigation would reveal the degree of clarification provided by various units in the treatment system. Operators of larger water treatment plants using surface waters as a source maintain detailed records of the quality of the intake water. Such records, when maintained over a period of many years, provide a historical resume of the chemical and biologic quality of the particular waterway.

Pond or Lake Eutrophication

The general procedures involved in a special study of a pond or lake eutrophication problem were detailed in the previous chapter under a discussion of pond and lake investigations. Such studies on eutrophication may be considered specialized investigations because the sole purpose may be to define the extent of eutrophication at present and proffer recommendations to alleviate the problem.

In studies conducted to determine the source of the eutrophication problem in Lake Sebasticook, Maine, industries and municipalities con-


LAKE WASSOOKEAG
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L WASSOOKEAG
1.
1A.
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CORUNDEL LAKE
MOOSEHEAD
MILL POND
3.
CORINNA
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4.
ALDER STREAM
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MULLIGAN STREAM
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Figure 5. Tributary stream station selection for a lake eutrophication study.

tributing to the inflowing nutrients were sampled on a 24-hour basis to determine the pounds of nitrogen and phosphorus contribution from each major source. Samples from inflowing tributary streams were also analyzed for nutrient composition and, when adjusted to a measured flow, indicated the amounts of major nutrients entering the Lake during the four seasonal sampling times. Samples also were collected vertically from top to bottom at five locations in the 4,200 acre Lake. Field studies were conducted during the ice cover season of February, as well as in May, August and November.

Water samples for organic nitrogen, ammonia nitrogen, nitrate nitrogen, and total and dissolved phosphorus were acid-fixed and shipped to a stationary laboratory for analyses. Plankton samples were collected also at all flowing and standing water stations and were preserved with 4 percent formalin and shipped to a stationary laboratory for later examination. Phytoplankton counts were made with the Sedgwick-Rafter counting cell following the procedures in "Standards Methods for the Examination of Water and Waste Water." Microscopic measurements were made of a selected number of predominant algae and the wet algal volume was determined in parts per million by multiplying the number of organisms observed per milliliter by the average species volume in cubic microns times 10^{-6}.

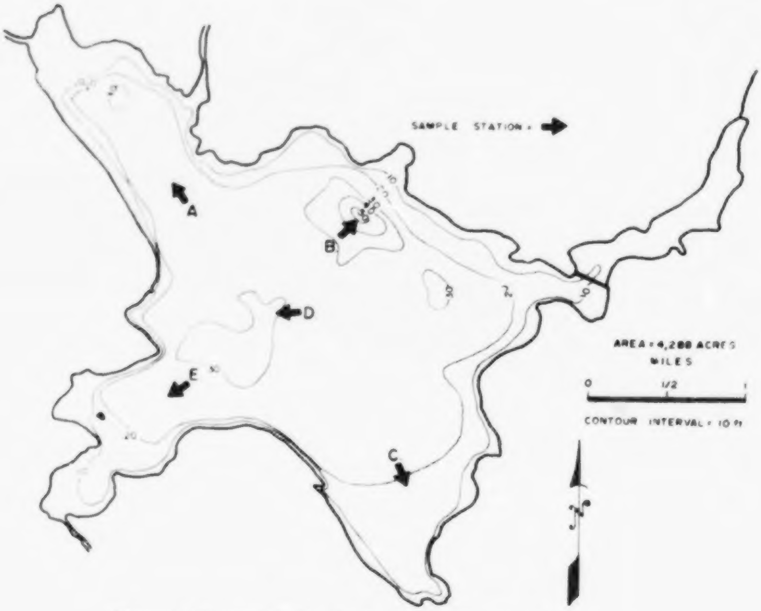


Figure 6. Lake station selection for a lake eutrophication study.

Chlorophyll bearing cells were filtered from the water with a 0.45 micron pore membrane filter and the filter and cells were placed in vials of acetone for the extraction of the pigments and for solution of the filters. Samples were then centrifuged to remove particulate suspended materials. The clear supernatant pigment-bearing acetone was examined on a recording spectrophotometer and the quantity of chlorophyll determined.

Lake sediments were examined for carbon, nitrogen and phosphorus content, as well as for diatom remains. Calculations were made of the amounts of major nutrients contained in the algal population. Estimates were made also on the amounts of nutrients draining directly to the Lake from peripherally placed septic tanks, from the use of fertilizers on adjacent fields, and from the groundwater. A vertical temperature and dissolved oxygen series were taken during each survey, and the early November samples coincided with the period of the fall overturn. Samples of the benthos population taken from defined transection points were collected during each of the studies.

Sewage Treatment Systems

The vast majority of municipal sewage treatment facilities employ biological processes for the treatment of domestic wastes. The purpose of the facility under these conditions is to provide an artificial environment, as ideal as practicable, for the organisms to accomplish the same task that would otherwise be accomplished if the wastes were discharged untreated into a receiving water. Because it has been designed for maximum efficiency, a sewage treatment facility will accomplish the waste water modification in a small controlled area, whereas it otherwise would be accomplished over a considerable length of stream or area of standing water body in the natural environment. In addition, preventative measures are taken in the sewage treatment facility to destroy pathogenic bacteria and protect the health and welfare of water users, as well as prevent environmental degradation that would otherwise be caused by the introduction of biodegradable wastes. Problems can arise in sewage treatment installations when conditions occur that effect an imbalance of the biota attacking the waste material in a manner similar to those occurrences that produce biologic nuisance problems in the natural environment. An investigation and surveillance of the biota in a sewage treatment installation can often predict such occurrences and recommend measures to prevent a malfunctioning of the facility.

Bacterial and other colorless plants initiate the breakdown of organic substances while particular organic substances are attacked by particular species. Generally there is a large number of bacterial species in any waste disposal unit. Most of the lower plants and animals found in

Plate 23. The supply of food constantly to a trickling filter provides an ideal environment for organisms to stabilize sewage.

sewage treatment are cosmopolitan in occurrence. They are well known and seem to be substantially alike in similar treatment plants. Some organisms however tend to occur very abundantly in certain types of wastes so much so that blooms of them can be called indicative for the waste and for the condition it causes. The dominance of any particular species is an organism response to some particular component or condition of the waste. Only a few chlorophyll-containing types can utilize the dissolved organic substances in sewage, raw or partly digested, and these then become of value as indicators of particular conditions.

Visible active inhabitants of anaerobic habitats, Imhoff tanks and digesters, are generally bacteria, together with about 20 species of protozoa.

Often the protozoa are extremely scarce. It has been stated that it is probable that these organisms afford a fair criterion to the proper working conditions in an Imhoff tank. When the tanks foam or seem to digest poorly, the number of protozoa is high and when there is but little solid matter in the liquid the number of protozoa tends to be small.

Biotic populations in trickling filters include bacteria, fungi, protozoans, algae, nematodes, rotifers, snails, sludgeworms, and larvae of certain insects. In this environment, animals exert a dominant influence by consuming bacteria to the extent that, when the filter is operating effectively, the bacteria are always growing and reproducing and the bacterial population never levels off. Worms and certain insect larvae serve as scouring organisms and burrow in the film of the filters, thereby keeping it loose and porous and capable of unloading to maintain effective biotic digestion.

Trickling filters are often troubled seriously by *Psychoda* flies, the "trickling filter fly." These small flies tend to reproduce in great abundance where there is high relatively humidity, oxygen, and organic materials that furnish food for the larvae. The flies do not sting or suck blood but they are a real annoyance because they settle on the eyes, ears, nose, and clothes, and because of their small size they easily enter surrounding houses. Control of the filter fly is provided by keeping the weeds and grass mowed short throughout the sewage treatment plant area, spraying the walls and other structures that are inhabited by the flies with an insecticide, and, if necessary, spraying the edges and walls of sludge drying beds similarly.

Protozoa are dominant in the biota affecting treatment in an activated sludge unit. Protozoa can be observed readily through the use of a low power on a microscope and, with experience, an investigator can determine the effectiveness of a particular activated sludge by the relative predominance of various types of protozoan inhabitants.

Stabilization ponds are used by a large number of municipalities throughout the United States for the stabilization of domestic wastes, as well as by many types of industries for the treatment of industrial wastes. Treatment efficiencies in stabilization ponds vary with indications that well-designed and well-operated ponds produce effluents equal to or better than those expected from effective conventional secondary treatment plants. The prevailing climate is an important factor in waste stabilization in an outdoor pond. Pond construction, location, and the types and loading of wastes that are introduced are likewise constraining factors on operating efficiency. Photosynthesis has been termed the most important single factor in determining the course and effectiveness of stabilization pond treatment. Algae are an intricate part of photosynthesis. Bacteria attack the liquid wastes in an environment that is dominated by the algal flora, and bottom organisms, usually midge larvae, assist in the stabilization of settled solids.

A stabilization pond environment is a confined ecosystem for the study or demonstration of aquatic interrelationships among organisms. A bountiful microscopic life abounds in an organically enriched, well-operating stabilization pond. Of course, certain precautions must be taken by the investigator to prevent the possibility of infection from pathogenic bacteria or other disease-producing organisms.

Under certain conditions, blue-green algal masses may form on the surface of the stabilization pond and these give rise to pigpen-like odors.

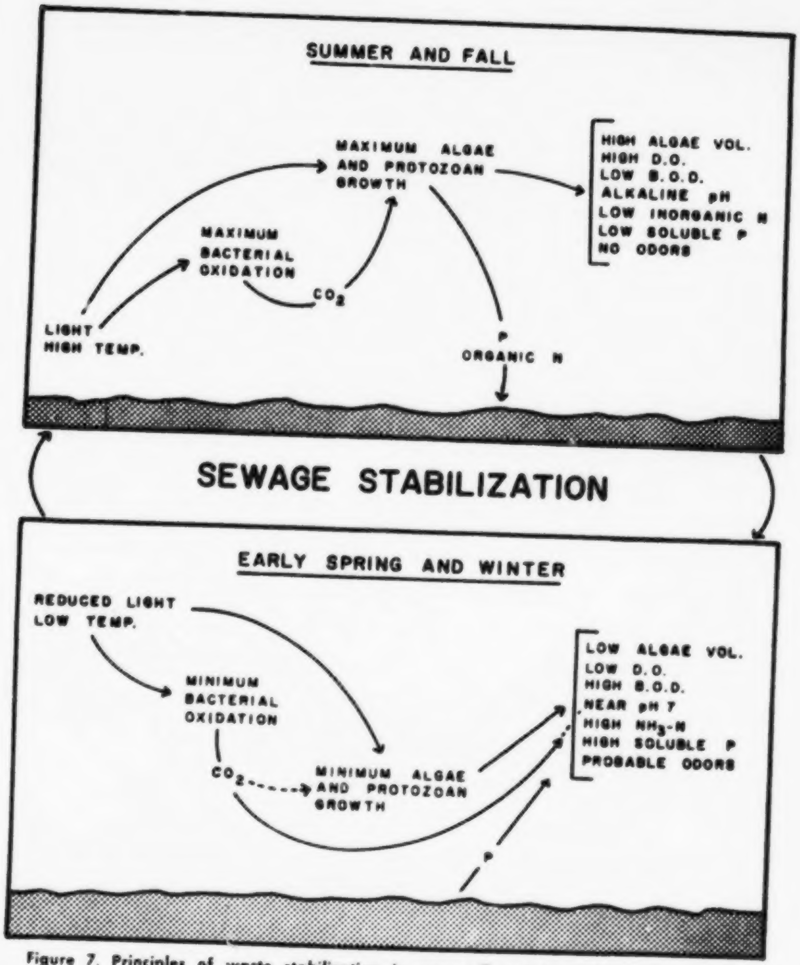

SUMMER AND FALL
MAXIMUM ALGAE AND PROTOZOAN GROWTH
HIGH ALGAE VOL.
HIGH D.O.
LOW B.O.D.
ALKALINE pH
LOW INORGANIC N
LOW SOLUBLE P
NO ODORS
MAXIMUM BACTERIAL OXIDATION
CO2
LIGHT
HIGH TEMP.
P
ORGANIC N
SEWAGE STABILIZATION
EARLY SPRING AND WINTER
REDUCED LIGHT
LOW TEMP.
MINIMUM BACTERIAL OXIDATION
CO2
MINIMUM ALGAE AND PROTOZOAN GROWTH
LOW ALGAE VOL.
LOW D.O.
HIGH B.O.D.
NEAR pH 7
HIGH NH3-N
HIGH SOLUBLE P
PROBABLE ODORS
P

Figure 7. Principles of waste stabilization in area affected by cold winter climate.

Blue-green algal masses may be carried to the leeward shore by wind and under a hot sun the surface of the mass will bake and decompose. The causes of such a phenomenon cannot be stated with specificity but the organic loading to the pond is an important factor. There are several avenues of approach that are available to combat odors arising from blue-green algal and other solids on the surface of stabilization ponds. These include skimming off the floating solids and burial on shore. In some cases the solid mass may be broken up with the application of a hard spray of water from a pump and fire hose-type spray nozzle or by running a boat with an outboard motor through the nuisance area. When the solids are broken up the odorous condition is temporarily alleviated because of increased bacterial action and aerobic oxidation of the solid masses. Continual surveillance must be instituted to preclude a regrouping of the floating mass. During the early stages of the formation of a floating algal mass, it may be controlled through the periodic use of an algal-killing chemical such as copper sulfate. The copper tends to kill the blue-green algae more effectively than the green algal species and thus the pond operation is not damaged severely by the treatment.

In the control of blue-green algae in a stabilization pond, floating sun-baked masses should first be removed from the surface and buried. With a methyl orange alkalinity of less than 50 mg/l, a calculated dose of 0.5 ppm commercial copper sulfate is used. With higher alkalinity, 1-ppm copper sulfate is applied, thus, for a high alkalinity pond that is 4-feet deep, 10 pounds of commercial grade copper sulfate per acre is required. The application may need to be repeated throughout the summer months and perhaps as often as every two weeks. The copper sulfate may be applied as a spray over the surface of the pond or by placing crystals in a burlap bag and dragging the bag through the nuisance area until the copper sulfate crystals are dissolved. The pond should be observed closely following any treatment to ascertain that the purpose for which the pond was initially designed is not seriously impaired.

11

Recovery from Catastrophe

Concepts

"HOW long after clean up will it be before the water is fit for swimming, fishing, or aesthetic enjoyment?" This oft-asked question actually is a phase of prediction based on the observed facts that become evident from a water quality investigation. Often the prediction is a part of the formal water quality investigator's report and an attempt to answer this question accurately should be made by the investigator at the completion of the study and the analyses of the data.

The question is not an easy one to answer because the answer depends upon a great number of interacting factors that combine to form what might be termed the recovery of a waterway from the effects of pollution or from a naturally occurring catastrophic event. For one thing, the water quality necessary to support swimming, fishing or aesthetic enjoyment can be slightly different depending upon the chosen recreational pursuit. As a result, the recovery process may differ, one from the other, and the length of time necessary for recovery likewise will differ.

As discussed earlier, each waterway is a unique microcosm comprised of physical, chemical, and biological interacting factors. For this reason alone, the recovery of the waterway from a particular catastrophic occurrence will be dissimilar both in the particular events leading toward recovery and also in the length of time required for the recovery process.

Theoretically, the recovery of a waterway that is not influenced significantly by tributaries or other similarly-acting factors, and from which a significant source of pollution has been removed, should proceed toward recovery with a shortening of the pollution zones. The downstream or horizonally-located zone of recovery should move upstream and gradually replace the zone of active decomposition. Eventually a similar process should occur in the zone of degradation. The adjacent downstream or more distant clean-water zone likewise should follow and eventually replace the zone of recovery when the effects of the insult on the aquatic environment have been obliterated. A succession of organisms would occur in the polluted area beginning with the bacteria and associated protozoa and algae and extending through the macrobenthos, which would include the sludgeworms, midge larvae, fingernail clams, sowbugs, leeches, dragonfly nymphs, caddisfly larvae and other gill-breathing insect larvae in that order. Eventually a population of fish and other aquatic life would be present that would be indistinguishable in population characteristics from an area of the waterway that remained unaffected by pollution. Often the events in nature do not occur in this logical sequence, however, because of the interaction of the many factors that will be discussed later. It is this process of interaction that complicates the predictability of natural phenomena that in combination produce waterway recovery.

Influencing Factors

Significant influencing factors in the waterway recovery process include the extensiveness of environmental damage, the length of time that the environment has been degraded, the environments affected, and the possibilities for infiltration of biota.

The extensiveness of environmental damage to a particular waterway habitat is different for each cause of environmental destruction. Such damage may be subtle and may affect only one or a few species of the most sensitive organisms within the aquatic community. The other extreme would be virtual destruction of the community of plants and animals within a given reach of waterway. An innumerable number of possibilities for different environmental gradations exist between these two extremes.

The cause of the environmental destruction may have been continuous, intermittent, fluctuating in degree, seasonal, annual, or occurring once in 10, 50, or 100 years. Each action will produce a different reaction within the aquatic community.

The history of the environmental degradation or the length of time that such degradation has occurred will tend to affect the length of time required for recovery. For example a lake that has become eutrophic within the past decade, and within which the process has been a gradual one, will recover in a much shorter time span than a lake with a long history of eutrophication.

The types of waterway environments affected by a particular catastrophe will affect the time required for recovery when the catastrophe subsides or has been controlled. The flowing water environment will react differently from that of the non-flowing water environment.

When pollution has been removed or controlled in a flowing stream, recovery often is aided by certain natural phenomena that occur seasonally or at more or less defined intervals. A spring flood for example will remove sludge deposits or dilute and wash away the residual pockets of toxic materials that may remain from a source of toxic pollution. This cleansing effect will prepare a physical habitat that is more suitable for colonization and inhabitation by organisms than one associated with a polluted environment. If nutrients have been a problem in the stream environment, these too are diluted and cleansed from the area by the forces and actions of spring freshets. Should the expected spring floods fail to occur because of prevailing area drought conditions, the time of recovery for a flowing water environment may well be extended for one or two additional years.

Expected recovery in the non-flowing environment generally will require a longer period of time than expected recovery within the flowing environment. Sludge deposits and their resultant environmentally deleterious effects are not easily removed by floods or spring freshets. Quite often the effects of such deposits must be minimized through the natural blanketing of such areas with naturally occurring materials that are environmentally more acceptable. The covering-over process is a much slower one than the attrition caused by flooding and may require several years to complete. In the interim, biological degradation of the sludge bank continues with some deleterious environmental effects that are diminished progressively with the healing influence of time.

Recovery within the non-flowing environment depends to a large extent on the flow-through time or water retention time of the pond, lake, or reservoir. For example, the flow-through time for Lake Michigan is approximately 15 times the flow-through time for Lake Erie. The theorétical recovery time following a similar degree of abatement of a similar pollutional load would approximate a ratio of 15 to 1 with Lake Erie experiencing the more rapid recovery. The physical topography of a water basin affects its retention time and significant factors include the length, width, depth, contour of the bottom, physical location of inflowing and outflowing streams, volume of water within the holding basin compared to the annual volume of inflowing water, water temperature, and a number of other related factors.

Probably the most significant pollution problem associated with lakes is that of eutrophication. All natural lakes through geologic time tend to mature, become more fertile, eventually fill with organic materials, and ultimately return to the landscape as dry land. This aging process has been accelerated in a great number of lakes through the activities of man. The nutrients, principally in the form of available nitrogen and phosphorus, that reach a lake basin through discharges of pollution to the basin or to the drainage area result in increased algal and vascular plant nuisances. These have contributed to an accelerated accumulation of organic materials and the general process associated with a lake becoming overenriched before its geologic time has been referred to as cultural eutrophication.

Once nutrients are removed from the lake or its drainage basin through processes of advanced waste treatment or other controls, lake recovery will begin. It may not be possible ever to bring the condition of a lake back to a point on the geologic timescale when the cultural eutrophication process was initiated. It should be possible, on the other hand, to recover a waterway to such an extent that many valuable decades of multi-water use can be obtained for a citizenry that has displayed an innate affinity for association with the water environment.

The fourth significant factor influencing recovery is the possibilities for infiltration of organisms into the organism-depleted environment. These possibilities include downstream drift, upstream migration, general invasion from adjacent areas as in a lake, egg deposition of those aquatic organisms that have terrestrial adults, infiltration by wind-borne algae and other organisms, transportation of aquatic weeds, algae, and microorganisms by birds and mammals, and the influences of man in transporting and transplanting aquatic organisms intentionally or unintentionally, into an otherwise denuded area.

Infiltrating Mechanisms

Waterway recovery begins with the removal of pollution or with its control through more adequate treatment or by other means. When the recruitment of organisms from adjacent or upstream areas does not occur, the principal process of establishing a biotic community within an area where the previous community has been virtually destroyed is through ecological succession. In the process of succession, bacteria from the soil and those introduced from the atmosphere convert the organic materials present to protoplasm and serve as a food supply for protozoa and other microscopic organisms. Simultaneously minute algae contribute similarly to the development of an environment that will be amenable to the life processes of higher and more complex biotic forms. When the environment attains a quality that will support their existence, other organisms will appear. Each type of organism in turn, will influence the aquatic environment and prepare it for the invasion of a higher form of life, which culminates in a balanced fish population. In an undisturbed aquatic environment the predator fish will assume the role of dominant organisms and will control the biotic population to the advantage of their species.

The type or combination of recruitment activities to fill a biotic environmental void is an important determinant of the time interval required for recovery. The downstream drift of organisms from upstream riffle areas or from tributaries may attain rates of many pounds per day and may serve to repopulate an area rapidly providing conditions for existence are acceptable for the survival of the species. The downstream drift of organisms is a common occurrence but there is evidence that the greatest drift may occur during the non-daylight hours. Downstream drift is common among insect larvae and occurs when the immature forms become released from their points of attachment and drift with the current.

Upstream migration of organisms is another phenomenon that is not as effective as downstream drift in the repopulation of an area but, nevertheless, is a significant factor. Evidence indicates that the amount of downstream drift far exceeds the amount of upstream migration for a given stream reach. In a lake environment, repopulation can be aided to a great extent from a general invasion by organisms from adjacent lake areas. Presumably the invasion would be from all sides accessible and would occur when conditions for existence would support the organisms, and in accordance with their general adaptability for locomotion.

Egg deposition can be a significant means of repopulating an area particularly by those species of organisms that have a terrestrial adult stage. When the chemical water quality is returned to an acceptable level for the survival of immature insect forms, the forms usually will be present within the environment following the time of the next egg-laying period for the species. Thus, a flowing water area would tend to become repopulated with invertebrates within a maximal period of one year following a corrected or controlled catastrophic occurrence. The interval of time might be decreased depending upon the possibilities of downstream drift or upstream migration or general invasion. The lake or pond environment is more complex and depends upon a number of related factors and the recovery period probably would be longer.

Algae and other microscopic organisms are found in the atmosphere and may be transported over great distances by the winds. This is a major reason why algae may be found in practically every habitat known to man. Birds are a significant transporter of fragments of aquatic vascular plants, algae, and other microscopic organisms. Such organisms may be carried in the intestinal tract of birds or as passengers on feet or beaks. When birds alight upon the water such organisms are dislodged and can mature in the new environment. Certain mammals also, particularly those that are associated with the aquatic environment, can transport algae, aquatic vascular plants, and other aquatic microorganisms. Man himself plays an important part by his practice of intentional or accidental planting or introducing various species into aquatic habitats. Often such species, unencumbered by natural enemies, become a severe pest and result in the expenditures of large sums of money aimed toward their eradication or control. Notably examples of such introductions that have become significant pest species include the german carp, Eurasian water milfoil and the Asiatic clam. The occurrence of certain other species in southern waters of the United States that are pests in more tropical climes is a matter of grave concern and current investigation.

Environmental Catastrophes

Environmental catastrophes may occur as a result of pollution or as a result of natural phenomena. The nature and extent of such catastrophes determine the time and other conditions necessary for environmental recovery. Catastrophes arising from pollution may assume many forms and degrees. Principally they may be confined to those from organic wastes, toxic wastes, inert silts, nutrients, heat, and oil. Catastrophes arising from natural phenomena likewise occur in a wide variety of forms and degree. Generally these may be attributed to floods, drought, ice, seasonal climatic conditions, and winds.

Brinkhurst (1964) observed the recovery of a British river from gross organic pollution that was alleviated with the operation of a new sewage treatment plant, and cooling towers and a recirculating system to deal with hot water discharges. According to his observations the river bed was carpeted with sewage fungus and inhabited by sludgeworms alone prior to the institution of pollution control devices. Deep accumulations of sludge were present. It was considered problematical that it would take some time for the sludge to disperse and that the recovery of the invertebrate fauna would be gradual and progressive. However, this prognostication proved to be pessimistic. Pollution control devices became operational in April, 1958. Later that spring the sludge was swept away by winter flood waters and the river was very greatly improved biologically. By September 1958 water quality had improved to such an extent that more resistant mayfly nymphs were able to survive along with sowbugs, various leeches, and midge larvae. In this case a pollution catastrophe was aided by a natural catastrophe in the process of environmental recovery.

Brinkhurst cites several examples of stream recovery following a reduction or control of severe pollution. Generally, according to the evidence submitted, recovery of a normally denuded area is rapid for those organisms that are mobile, but a much longer time is necessary for slow-moving species to recolonize such an area. Often several years will be required for molluscs to reappear. Aerial imaginal stages of aquatic insect larvae were able to lay eggs in a river in the course of the ensuing breeding season in a great number of cases. If flood waters are not able to dislodge the accumulated sludges, stream recovery will require a much longer time period.

The introduction of toxic materials will kill a portion or all of the animals within the affected reach of the water environment depending upon the relative toxicity of the introduced materials. Hopkins et al.

(1966) investigated the effects of insecticides on aquatic fauna in waters draining a treated pasture land. There resulted a considerable mortality among aquatic insects in the treated area although there was no evidence of mortality among fresh-water crayfish and fish. After 12 months following treatment, large numbers of aquatic insects were again found in the streams but the species composition was entirely different from that present before treatment with the insecticide.

Studies have been made on stream faunal recovery after reclamation of manganese strip mining operations in Virginia. Faunal recovery in the reclaimed stream was complete six years after reclamation of the surface mining spoils. Partial reclamation was found to be ineffective in bringing about faunal recovery or changing the turbidity and silt load of affected waters. Intermediate samples before the six-year time period were not obtained and it was therefore impossible to determine the earliest time of stream recovery.

Stuart (1953) conducted studies on the effects of siltation on trout redds and very young trout. He concluded from his studies that silt is not very dangerous in the normal stream if excess occurs only at intervals. The character of such normal streams can, however, be altered drastically by allowing the washings of quarries, gravel pits, and mines to flow into streams untreated. In many cases the quantities allowed to enter the streams may be small and the material in suspension may in itself be of a non-toxic character. But, continuous applications of small quantities over the redds were found to be much more detrimental to the welfare of the very small fish than sudden flushes of large quantities of silt. Stuart found that the continuous addition of fresh sediment resulted in serious gill membrane inflammation, which eventually caused death. Intermittent additions did not cause death. Wilson (1957) studied the effects of gold dredging operations on bottom-associated organisms in the Powder River of Oregon. During siltation, production of fish food organisms dropped to almost nil in the zone of heaviest pollution. Between 15 and 20 miles of the River were heavily silted. In about one year after the dredge closed operations, there was a remarkable recovery of bottom life. Silt was flushed from the pools and riffles by freshets and bottom organisms increased eight to ten fold in weight per unit of bottom area.

As discussed earlier, nutrients contribute to the eutrophication of standing water bodies. The recovery of a lake from eutrophication following the removal or reduction in nutrient inflows is a complex process. The control of the nutrients stimulating the plant growth is seldom complete because of the residual naturally-occurring nutrient inflows from the drainage basin, groundwaters, and atmospheric washouts. In addition, a substantial portion of the nutrients that have been contributed by pollution over the years are bound in benthic sediments and comprise a part of the biotic population. A portion of the nutrients found in benthic sediments may be recycled to the superimposed water when conditions for such recharge are suitable. The nutrients occurring in the benthic population are released upon the death and decay of the organisms. A portion of these may be recycled in the aquatic food web, whereas the remaining portion may be transported to the bottom sediments where a small portion only may be available for future recycling. When eutrophication has been severe and has existed for a considerable period of time, the speciation of the fish population usually has changed. Carp and other rough fish are found in abundance in fertile eutrophic waters. Midge larvae also are found in the rich organic sediments. The finer, more sensitive fish species generally are eliminated with the onset of eutrophication. Often this is a result of a depletion of oxygen in the lower limits of the thermocline and beneath where the temperature is suitable for such fish.

The recovery of a lake from the degrading effects of eutrophication is a slow process of attrition of the nutrient supply. Bottom sediments may be covered with inert silts that serve to segregate the organic materials from the superimposed water. In time, the nutrients that are recycled within the biomass decrease. With the death and decomposition of organisms a portion of the nutrients combines with the consolidated benthic sediments and does not recharge to the superimposed water. Nutrients are discharged continually in the lake's effluent and there the flow-through time of the water in the lake basin is an important factor in determining the time necessary for lake recovery. When the flow-through time is a few months or two or three years, the recovery rate from eutrophication should be rapid following the control of nutrient inflows. If the flow-through time is 10, 20 or 100 years, the length of anticipated recovery time will be great. Examples of lake environments that have shown substantial recovery following the removal of pollution sources of nutrients include Lake Washington near Seattle and Lake Monona near Madison, Wisconsin.

Heat and oil each produce their unrelated effects upon the receiving aquatic environment. The dissipation or degradation of these materials will result in biotic recovery that will follow the principles discussed above.

Natural phenomena such as floods will produce a scouring action that may wash away substantial quantities or virtually all of the invertebrate fauna of a flowing waterway. Drought conditions reduce stream flows and expose productive marginal areas of lakes, ponds, and streams to the baking effects of the sun. Adverse water quality characteristics that virtually may be unrecognized during normal flow times become accentuated in their effects during conditions of drought. Ice formations sometimes produce their toll on benthic life by gouging out shoreline areas and occasionally by destroying the habitat for benthos with the formation of stream bed ice where both the surface and stream bed become solid ice sheets with the water flowing between. These conditions occur only in extremely cold weather in northern climes. Recovery from these natural phenomena follow similar principles to those described above. The repopulation by mobile forms is rapid whereas the repopulation by those forms not carried by the current, and which are relatively non-mobile, is slow.

Wind as a natural phenomenon occasionally has its deleterious impact upon the aquatic environment. High winds and other phenomena associated with hurricanes in coastal waters produce changes in flow and in the distribution of fresh-water and salt-water in the coastal waterways. These changes have a deleterious effect particularly on those species that depend upon a certain chlorinity of the water for their existence. Recovery in these instances depends principally upon the life history of the species in question, the extent of damage, and the possibilities for repopulation through infiltration.

Water quality changes induced by the seasons can have their effects on macrobenthos and other organisms associated with the aquatic environment. Gaufin and Tarzwell (1955) studied environmental changes in a polluted stream during winter. In their studies they found that the decomposition and recovery zones were shortened during summer and that the effects of pollution were most evident and the life zones more clear cut and more readily observed during this time. In the winter months, the metabolic activity of the organisms is at a lower level and life zones become longer or tend to lose their identity. The pollutional carpet of bacteria, protozoa, and entrapped organic materials, which was characteristic of the zone of decomposition in summer, extended farther downstream during winter. Occasionally this carpet reached the upper end of the summer's clean water zone. During the winter months, bottom organisms characteristic of the decomposition and recovery zones during summer may appear at points much farther downstream.

The writer has made similar observations on numerous occasions during winter studies of polluted streams in northern Wisconsin. Although the observed effects on the macrobenthos of the zone of active decomposition may not be nearly as severe in winter as in summer, this zone may occur as many as 50 miles downstream in winter compared to 15 miles downstream from an organic pollution source in summer. In winter, under 18 inches of ice, the area affected by the active decomposition zone corresponded to the area defined as clean water in summer. Because of the organism's reduced metabolic rate during winter, the growth of *Sphaerotilus* and attendant pollution indicators did not seem to hamper a rapid recovery when the ice was removed and water temperature increased. In such northern ice-covered polluted streams, a particular area may appear polluted in winter and relatively unpolluted during the summer months. Judging from an examination of the benthic organisms, the reach of stream just downstream from the source of pollution may appear very polluted in summer and only relatively polluted in winter. Recovery within the macrobenthic population is rapid because all of the clean-water associated forms are not destroyed in winter. Destruction is handicapped by the organisms' reduced metabolism, and the rapid dissipation of adverse water quality effects with the warmer temperatures of summer.

12

Interpreting the Findings

Data Evaluation

THE evaluation of water quality from field investigative data is an exercise in judgment supported by mathematics and graphic display of organized data. Mathematics and graphic data displays are support tools for interpretation and should not be used at the exclusion of the judgment factor.

One who interprets data well continually tempers his confidence with doubt. Doubt stimulates a search for new and different methods of confirmation for reassurance. Such reasonable doubt is directed toward each step in the investigative procedure: Were the sampling stations located in the right general area to depict water quality within the stream or lake environment? Were a sufficient number of sampling stations used? Were the samples collected representative of water quality within the limits of available sampling technology? Were adequate measures employed to avoid contamination during the act of bacteriological sample collection? Were analyses completed for all water quality constituents vital to data interpretation? Were the correct analytical procedures followed in sample analyses? What would be the expected effect of the seasonal climate on the water quality sampled?

The correct expression in labeling data is vital to accurate data interpretation, as well as to later report preparation and even to the reading of the report. Already there is much confusion when reading reports and other literature regarding the forms of nitrogen and phosphorus that particular data represent. For example, nitrate is expressed in either the more common form as the elemental nitrogen (N) or as the radical nitrate (NO_3), which has a molecular weight that is 4.4 times the atomic weight of nitrogen. Phosphorus on the other hand commonly is reported as the radical phosphate (PO_4), but also may be reported as the elemental phosphorus (P) and occasionally as phosphorus pentoxide (P_2O_5). The element has an atomic weight less than one third the molecular weight of the phosphate radical. To convert from phosphate (PO_4) to phosphorus (P) the value must be multiplied by 0.326; to convert from phosphorus pentoxide (P_2O_5) to phosphorus (P) the value must be multiplied by 0.436. In addition it is frequently not indicated whether the stated value is representative of total, soluble, or some other form of phosphate or phosphorus. The total to soluble phosphorus ratios may vary from 2 to 17 or even 90, depending upon the particular water, season, aquatic plant populations, and probably other factors. These ratios are of value when they can be determined periodically within the same water body and changes in them correlated with volumetric response changes within the algal mass.

Iron commonly is reported merely as Fe without indicating whether it is in the ferrous or the ferric form. The distinction is important in interpretation of the iron data since ferrous iron uses dissolved oxygen and ferric iron does not. Failure to indicate whether the iron is in a total or dissolved state is frequent also. Total iron may include some indefinite portion of inert iron derived from silt in the water, which is dissolved by the acid used in the analyses. Dissolved iron is much more significant with respect to water quality than is total iron.

Data Organization

Organization of data in some orderly form is the first step in their interpretation. Data produced by the laboratory usually are tabulated most conveniently for laboratory personnel by date of sample collection, which is generally the order in which they are received in the laboratory for analyses. Chemical data may be combined for all stations under that date. The data must be reorganized by sampling stations for interpretation. A common basic table has the data for each station arranged chronologically by date of collection in the first column followed by columns indicating time of collection, stream discharge, and the concentrations of various water quality constituents.

Data for one or more years on a year-round basis, or for some other protracted period, should be separated into segments of similar flow and temperature combinations. Year-round data may be separated by seasons. Data that are obtained daily or several times weekly may be separated by months or combinations of 2 or 3 months with similar stream flow and temperature characteristics. The discharge of a seasonal industrial waste may govern the separation of data. Data for the same month from 2, 3, or more years may be combined. The important guiding principle is to include sufficient data for statistical reliability within relatively limited ranges of stream, lake, or pond characteristics. In a lake or pond environment it is often advantageous to group the data according to depth strata. In the stream environment, the more important considerations are temperature, stream flow, and seasonal waste discharges, if any.

Evaluation of data at an individual station may be aided materially by arranging the values in sequence of magnitude and plotting them as the frequency distribution on probability graph paper. The frequency distribution plotting on probability paper may be used to determine the mean value graphically by taking the point at which the straight line fitted to the points crosses the 50 percent frequency line. The standard deviation of the data and selected confidence limits also may by taken directly from the plotting. The logarithmic probability plotting is especially useful for obtaining a mean of coliform density data. This method minimizes the influence on the mean of occasional extremely high values in much the same manner as the geometric mean.

Constituent loads entering the waterway and in the stream can be evaluated most conveniently if constituent concentrations and stream and waste flows are converted to pounds per day. The concentration of the constituent in milligrams per liter (mg/l) multiplied by the flow in cubic feet per second multiplied by 5.4 will result in the weight of the constituent load in pounds per day passing a given point. Likewise, the concentration in mg/l times 8.34 times gallons per day times 10^{-6} will result in a pounds per day value. The gallons per minute times 2.228 times 10^{-3} equals cubic feet per second. The gallons per minute times 1440 equals gallons per day. These formula can be memorized quite easily and will be used many, many times in data interpretation. Their use may be reversed to express constituents in concentration when load weight designations are known.

Graphical representation of data is one of the simpliest and best methods for showing the influence of one variable on another. The best graphs are those that are most easily comprehended by the viewer. The degree of success of a presentation or report is very frequently correlated with the above-stated axiom.

Ordinary rectangular coordinate paper is satisfactory for most graphic purposes. Twenty lines per inch is recommended. Semilogarithmic paper is convenient when one of the coordinates is to be the logarithm of an observed variable. The independent and dependent variables should be plotted on the abscissa and ordinate in a manner that can be easily comprehended. The scales for graphic presentation should be chosen so that the value of each coordinate can be found quickly and easily. The plotted curve should cover as much of the graph paper as possible. The scales should be chosen so that the slope of the curve approaches unity as nearly as possible. Other things being equal, the variable should be chosen to give a plot that will be as nearly a straight line as possible.

The title of a graph should describe adequately the plot that it is intended to show, yet the ttile should contain the least number of words possible. A legend should be present on the graph to clarify any possible ambiguities that may be present to otherwise confuse the viewer. Information on the conditions under which the data were obtained that are demonstrated graphically should be included in the legion where possible or described in detail in a closely associated portion of the report.

In essence, data organization involves the least complex arrangement and display of the data that will aid in the interpretation of water quality and facilitate an understanding of conditions of existence within the waterway. Existing Federal-State water quality standards on interstate streams are a valuable adjunct in the interpretative process, as will be the effluent limitations and standards being developed presently for various industrial waste categories. Most States have extended their standards programs to include all intrastate waters. These programs have simplified the investigator's evaluation of data to some extent because the classification of stream uses and the associated water quality criteria contained within water quality standards provide an official basis against which to compare the investigative data collected. In addition, the helpful references provided in Chapter VI will serve as invaluable tools for any data interpretative process.

Selected Case Histories

Figure 8 represents data collected in 1963 on certain immature insect larvae collected from the Brule River that separates the States of Michigan and Wisconsin. The Brule River stream bed was composed of rock, rubble, and gravel with occasional sand. The current was swift and water depths ranged from 6 inches to 2 feet in the area sampled. About one year prior to the field investigation, the Iron River, a tributary of the Brule River, had received gross acid mine drainage pollution. At the time of sampling, there was a dense growth of filamentous green algae in the stream. Samples were collected in early August. River discharge at the mouth of the Brule River was 300 cubic feet per second during the sampling period.

The remaining effects of the earlier acid mine discharge was demonstrated graphically by the types of organisms selected for visual display. Caddisfly larvae are representative of a group of clean-water associated organisms generally intolerant of adverse environmental conditions. Midge larvae on the other hand, as a group, tolerate adverse environmental conditions to a much greater extent. The tolerance level of the particular genera of mayflies found in this survey is closely associated to that of the midge larvae. In the control station area, upstream

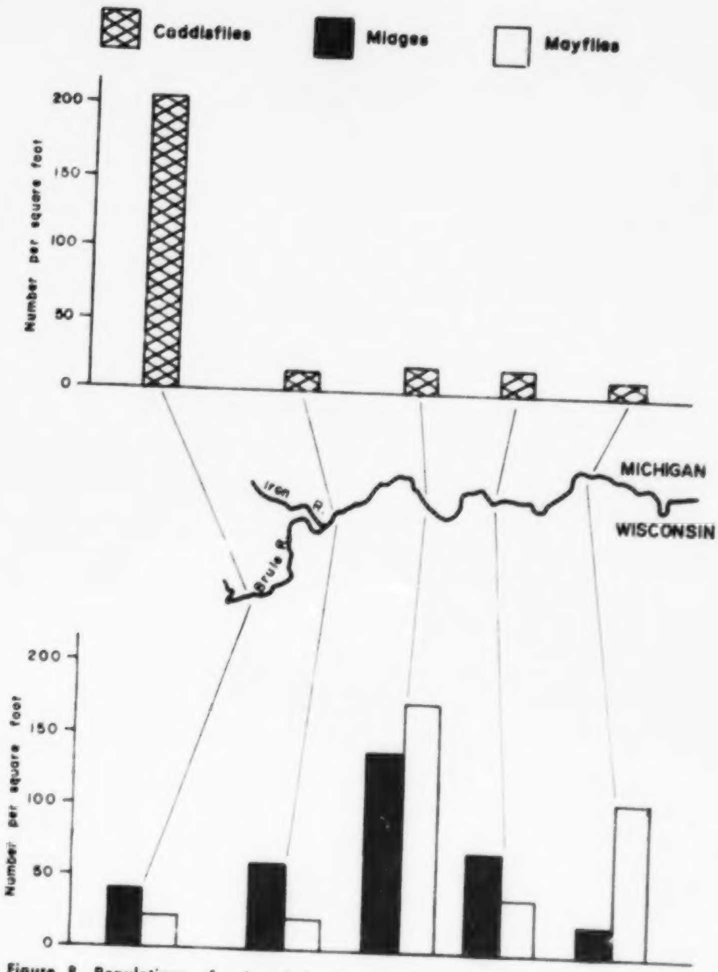


Figure 8. Populations of selected benthic organisms in the Brule River, 1963.

from the entrance of the Iron River to the Brule River, caddisfly larvae were found in abundance whereas the number of midge or mayfly immature forms was in the order of expected magnitude for the physical environment of the waterway. Downstream from the tributary Iron River, the effects of previous acid mine pollution were clearly evident. At some previous time the caddisfly larval population undoubtedly had been eliminated. The numbers of caddisfly larvae present during the survey in the downstream reaches of the Brule River were indicative of a population that could have been supplied by the downstream drift of organisms from areas upstream, as well as a water quality that then could be tolerated by certain individuals of the group. On the other hand, immature midges and mayflies increased in population density by several fold over the control station in reaches downstream from the Iron River tributary, which demonstrated the latent impact of nutrients to support the attached algal population. Iron can be a nutritive stimulant for algal growth. The mayfly larvae represented by the graphic display were those that can live in close association with abundant filamentous algae and secure their food supply in such an environment. The field investigation did not extend sufficiently far downstream to demonstrate recovery in the benthic population from the past environmental insult. Often it is not possible to demonstrate such recovery because of the discharge of the particular stream under investigation into a river where much greater dilution is afforded the waste materials, or of the presence of main stream reservoirs, which serve as giant stabilization basins for the introduced wastes.

The effects on benthos of the effluent from an overloaded sewage treatment plant are depicted in Figure 9. In the upstream environ-

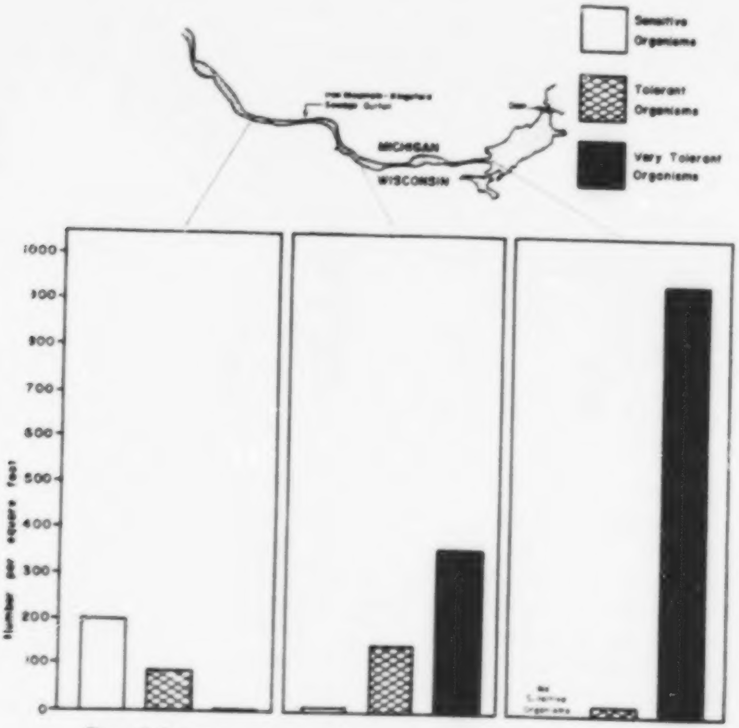


Figure 9. Bottom organism populations—Iron Mountain-Kingsford area, Menominee River, August, 1963.

ment, sensitive organisms predominated and very tolerant organisms were few in numbers. Organisms sensitive to organic wastes generally include immature stoneflies, caddisflies, mayflies, riffle beetles and hellgrammites. Organisms considered to be very tolerant toward organic wastes include sludgeworms, several species of midges with ventral blood gills, certain leeches and other worm-like organisms that are associated closely with this group. In between these two extremes are those organisms generally considered tolerant toward organic wastes. Tolerant organisms are those that do not appear to fit readily into either the sensitive or very tolerant group and include some of the midge larvae, sowbugs, many of the leeches, snails, clams, and many of the species of fly larvae. Two hundred yards downstream from the entrance of the sewage treatment plant effluent, a zone of degradation can be identified from the benthic population. Sensitive organisms, here, are reduced to a minimum. There is an increase in tolerant organisms and a substantial increase in the organisms very tolerant toward pollution. About 3 miles downstream, the river entered a reservoir, which served as a settling basin for the organic wastes. The settleable solids collected as an extensive sludge bed in the upper reaches of the reservoir and very tolerant sludgeworms increased in population to an excess of 900 per square foot. Sensitive organisms were entirely eliminated in this environment. Thus in a short reach of river, slightly over 3 miles, a benthic population of sensitive organisms was reduced from 200 per square foot to 0 and a population of very tolerant sludge-associated organisms was increased from very small numbers to that of abundance.

A clean water zone usually contains individuals of the tolerant and very tolerant group within the benthic population. Conversely, a polluted water zone usually contains no sensitive organisms but may contain tolerant and very tolerant organisms in varying numbers. When the dissolved oxygen is completely eliminated, even the very tolerant macroorganisms may be eliminated also, except for the possibility of those that are able to breathe air for their oxygen supply.

Sensitive organisms are found in lakes and reservoirs, as well as in streams. The benthic population in two reservoirs separated by eight stream miles and the effects of organic wastes from a paper-making industry are depicted in Figure 10. The population of bottom-associated organisms found in the upper reservoir was considered typical for a clean water environment and was composed of a well diversified organism complex containing immature caddisflies and mayflies. The organism assemblage in the downstream reservoir was one depicting a polluted environment. Sensitive benthos were eliminated. The sludgeworm population was increased to 700 organisms per square foot. Tolerant sowbugs, midges and fingernail clams were associated with the sludgeworms. Sludge and wood chips were found in areas of

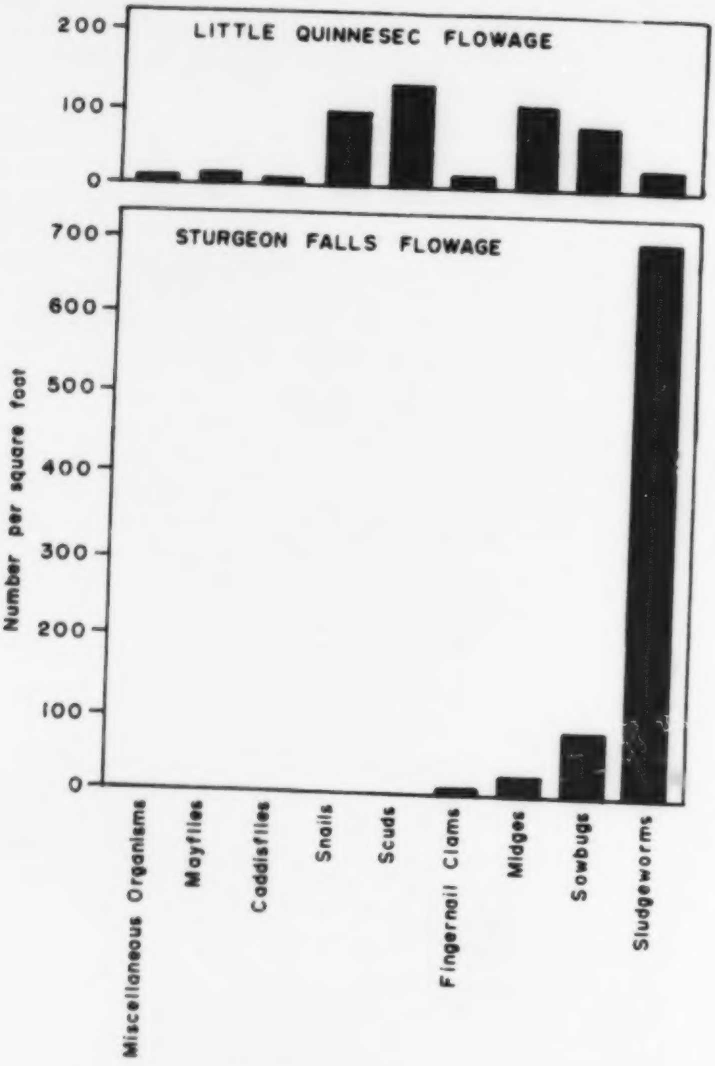


Figure 10. Comparison of bottom organism populations in two upper Menominee River reservoirs.

reduced current and wood fibers and slime bacteria were present. Benthic organisms in the downstream reservoir indicate a polluted environment whereas those organisms in the upstream reservoir indicate an environment that had not been degraded substantially by the activities of man.

The effects of inert inorganic solids on the benthos are illustrated in Figure 11. Demonstrated also by these data is a lack of immediate lateral mixing of a waste in a river such as the Potomac. Glass sand wastes were discharged to a stream approximately one-half mile upstream from its confluence with the Potomac River. Upstream from this junction, the sparkling clear Potomac was bedded with rock, rocky ledges, coarse gravel and some naturally occurring clean sand. Beds of rooted vegetation were plentiful. Gill-breathing snails and mayflies predominated in the invertebrate population and were found everywhere on the bottom substrate. Small fish were observed in abundance. Thirteen genera of bottom animals were represented in collections from the control station.

At a station 600 yards downstream, and on the same side as the confluence of the small creek receiving glass sand wastes with the Potomac River, the stream bed was devoid of visible animal life. Blue-green algae grew marginally on the wave-washed stream bank area. On the opposite side of the stream, 13 genera of animals were

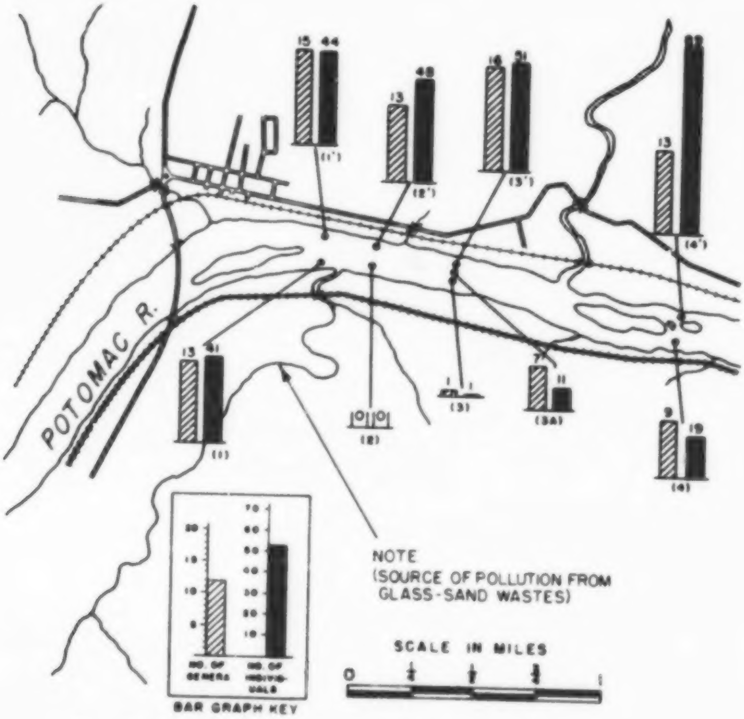

15 44
(1')
13 48
(2')
16 51
(3')
13
(4')
POTOMAC R.
13 41
(1)
0 0
(2)
1 1
(3)
7 11
(3A)
9 19
(4)
NOTE
(SOURCE OF POLLUTION FROM GLASS-SAND WASTES)
20
15
10
5
70
60
50
40
30
20
10
NO. OF GENERA
NO. OF INDIVIDUALS
BAR GRAPH KEY
SCALE IN MILES
0
¼
½
¾
1

Figure 11. Genera and population numbers of bottom animals per square foot in Potomac River, September, 1952.

found in bottom samples, which made the variation between the two sides of the stream a dramatic indication of the environmental effects of inert silts.

Downstream from this area the number of genera of benthos gradually increased, but the number of organisms per square foot of bottom material remained low. The 1952 survey was not extended to a reach that indicated stream recovery from the introduced wastes nor did the population of bottom organisms indicate lateral mixing of the stream waters at the downstream point of sampling. The shore waters opposite the introduction of the glass sand wastes maintained a similar benthic population both in numbers of genera and numbers of individuals and indicated that the effects of inert solids from this waste source had not extended beyond the mid point of the stream.

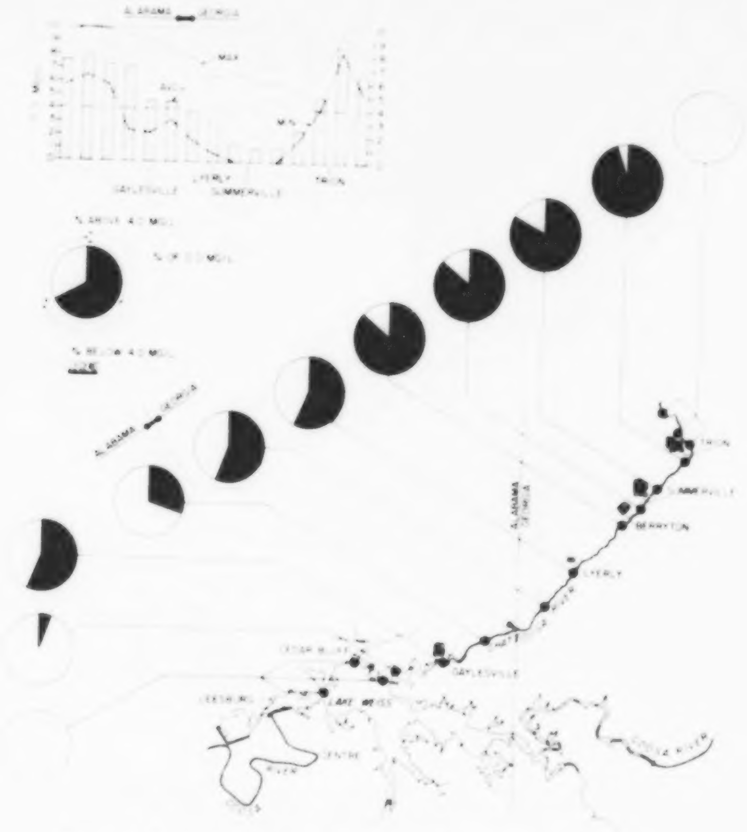


Figure 12. Dissolved oxygen in the Chattooga River showing the percentage D.O. below 4 mg/l, August 1962.

Studies have been made on the Chattooga River, which had a mean daily discharge of 94 c.f.s. from Trion, Georgia, to Lake Weiss in Alabama. Textile wastes and organic wastes entered the stream at Trion, Georgia, and organic wastes principally entered at Summerville, Georgia. Samples were collected daily for 14 days for dissolved oxygen concentrations. The dissolved oxygen of the stream was drastically reduced by introduced wastes and at times was eliminated (Figure 12). The data were graphically illustrated as the percent of samples that contained dissolved oxygen below 4.0 mg/1 (shown in black) and the remainder of the samples where the dissolved oxygen exceeded that number (white). This display of data is dramatic because a particular level or concentration of the water quality constituent can be chosen as an acceptable minimal criterion and the percentage of time that the criterion is violated can be shown. The violation of any criterion contained in Federal-State water quality standards on interstate streams could be dramatically pictured in this manner.

Twenty different kinds of stream bed associated animals, predominantly insects sensitive toward pollution, were found in the rocks and gravel upstream from Trion, Georgia. Three miles downstream, no stream bed animals were found (Figure 13). The color of the

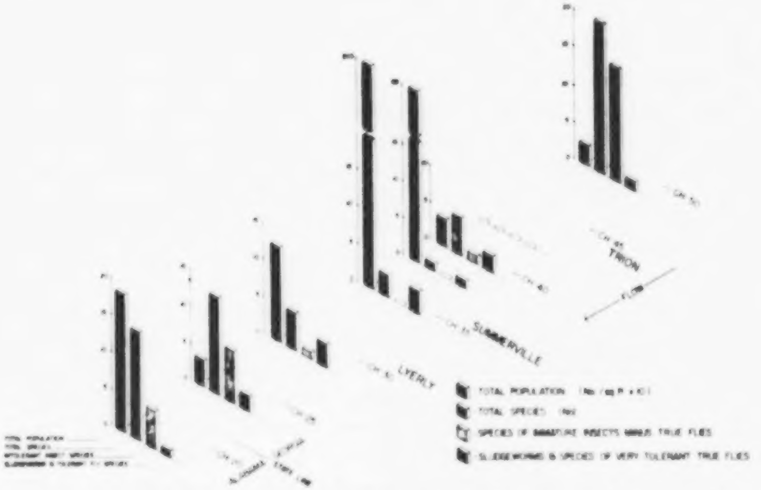


Figure 13. Stream bed animal population in Chattooga River, Georgia, August 1962.

River in the downstream area changed from day to day according to the type, volume, and intensity of dye materials included in the textile mill wastes. Changing from deep blue to black to brilliant green, it faded to less intense shades of grey and green downstream. A layer of black sludge covered the stream bottom where no organisms were found. Stream recovery began to occur about 20 miles downstream although a benthic population similar to that occurring in the control station area did not occur throughout the course of the 30-mile survey. Figure 13 illustrates a benthic fauna that has been subjected to severely toxic pollutants downstream from Trion. After a 5-mile flow distance the toxicity of the waste had been diluted sufficiently to permit the establishment of a minimal benthic population. Probably the population could have been established in this area by drift of organisms from upstream clean water areas or tributaries during times when the water flowing above the toxic sediments would permit such drifting organisms to live. As the toxicity subsided, the food materials in the organic sediments permitted the development of an abundant population of sludgeworms and associated midge larvae. The numbers of different kinds of benthic organisms, and in particular the species of sensitive organisms, did not show recovery for a distance of about 20 miles downstream from the source of pollution.

Toxic wastes may interfere with the natural clarification processes in water by reducing or eliminating those organisms that otherwise would break down the waste products. The character of the water and its mineral content can alter considerably the toxic effects of a given chemical or wastes. The combination of two or more metals can make them several times more toxic to aquatic life than when they occur singly in the environment.

Figure 14 depicts temperature and dissolved oxygen profiles obtained from sampling Lake Sebasticook, Maine. The May study was conducted just following the spring overturn and the November study was conducted during the fall overturn when the entire water volume of the lake was being mixed by winds. Dissolved oxygen was present from surface to bottom. Especially during the November study, the temperature did not vary from the water's surface to its bottom. During the latter part of July, Lake Sebasticook was stratified. The thermocline began at a depth of 32 feet and extended downward to 44 feet. The dissolved oxygen was less than 1 mg/l at the beginning of the thermocline and was 0 at a depth of 35 feet. Being stratified from the latter part of May, the deeper waters of the Lake could not receive oxygen from the atmosphere. Prolific growths of algae, and other organic materials, settle into these deeper waters from the waters near the surface and, during the process of decomposition of these materials, the dissolved oxygen present on May 20 was gradually

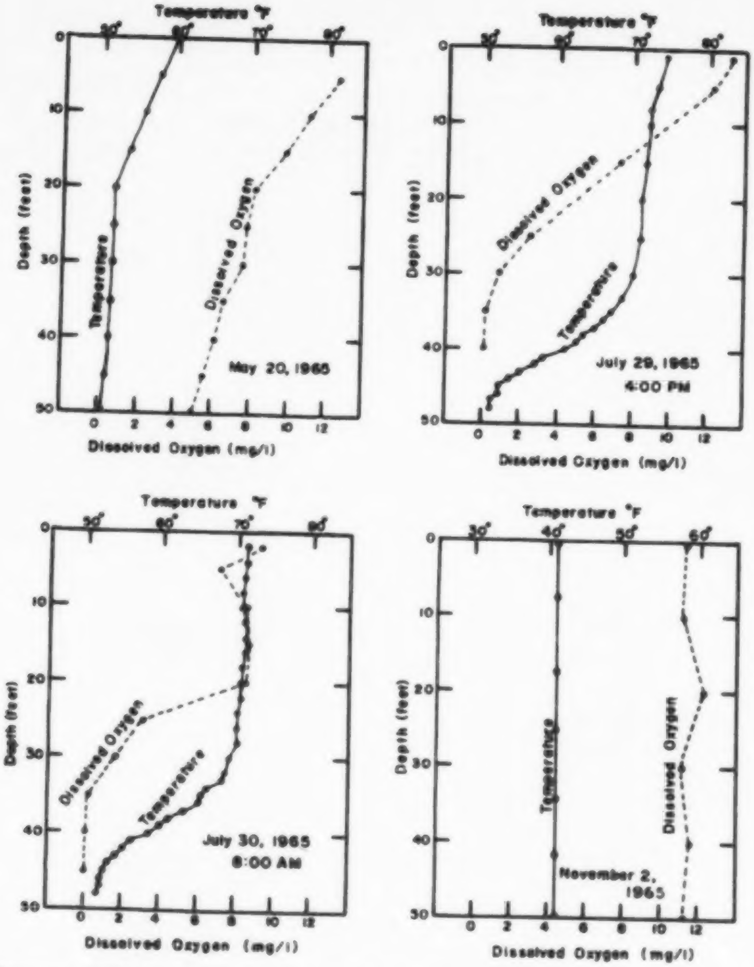


Figure 14. Vertical temperature and dissolved oxygen profiles, Lake Sebasticook, Maine.

depleted from the deeper water area. Probably, as the summer advanced, the vertical zone of depleted dissolved oxygen would extend upward. The dissolved oxygen curve for the afternoon of July 29 and in the morning of July 30 had a different profile in the upper waters and reflected the effects of a large mass of algae that was present at that time.

Where historic data are available on the temperature and dissolved oxygen profiles within a lake, comparative calculations among specific years can be made of the volume of water within a particular portion of the profile. Through such a method, a judgment can be reached on the degree of eutrophic advancement within the water body.

Two additional methods of data display are illustrated in Figures 15 and 16. In Figure 15 the downstream increase in chlorophyll *a* is illustrated by the diameters of circles that are associated with

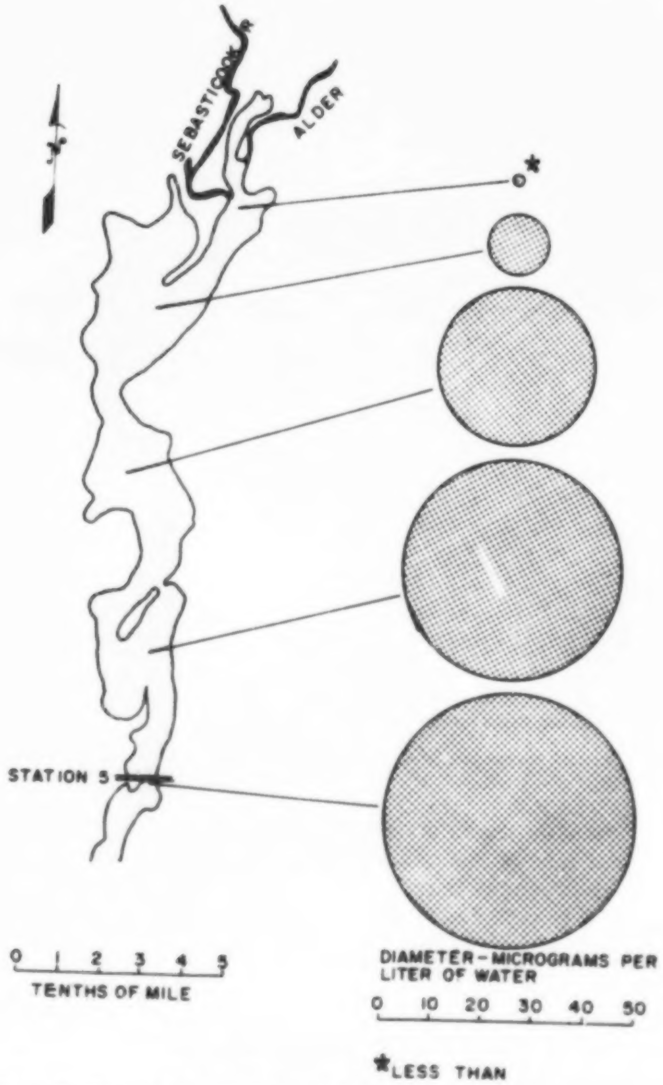
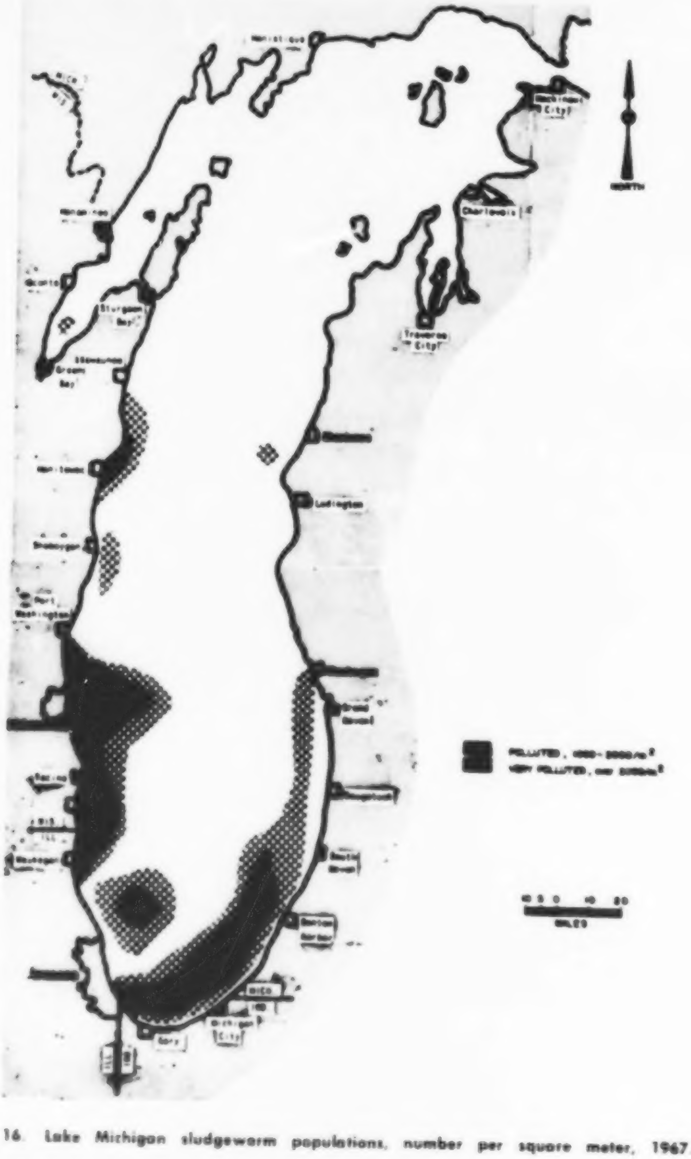

SEBASTICOOK R.
ALDER
N
0*
STATION 5
0 1 2 3 4 5
TENTHS OF MILE
DIAMETER – MICROGRAMS PER LITER OF WATER
0 10 20 30 40 50
*LESS THAN

Figure 15. Chlorophyll concentrations in stabilization area of Sebasticook River

particular stations throughout an area of sluggish water that was heavily loaded with organic materials. The grossly polluted water entering the upstream portion of the stabilization area supported very few algae. As the water became less polluted through the settling of suspended solids and the decomposition and stabilization of the



Manistique
Menominee
Mackinaw City
NORTH
Charlevoix
Oconto
Sturgeon Bay
Kewaunee
Green Bay
Traverse City
Manitowoc
Ludington
Sheboygan
Port Washington
Grand Haven
POLLUTED, 1000-5000/m²
VERY POLLUTED, over 5000/m²
Racine
Kenosha
Benton Harbor
10 5 0 10 20
MILES
Michigan City
Gary

Figure 16. Lake Michigan sludgeworm populations, number per square meter, 1967.

organic materials, the algae increased substantially in numbers. The nutrients released by the decomposing wastes supplied the food to support the increased algal mass. The measurement of the chlorophyll provides comparative data on the density of the algal population.

Areas of polluted lake bed may be demonstrated by the sludgeworm population as in Figure 16. Lake sediments supporting population of sludgeworms greater than 100 per square foot (approximately 1,000 per square meter) have been associated with polluted bottom materials. The pollution in the case of Lake Michigan is the result of inflows of treated sewage and other wastes from shoreline developed areas.

13

Reporting the Results

REPORTING the findings is equally as important as any other aspect of problem solving. A report represents the end product of the investigation. It is often the only link between the field investigation which may take considerable time, money, and effort and the public or report recipient. A report usually recommends corrective actions to abate a problem and such efforts are necessary for problem solving and environmental enhancement. Thus, the report may be the most important part of a particular investigation especially because of the effects that it can have on broad political changes that may be focused on the problem area.

Good report writing is a systematic recording of organized thought. Good technical writing is clear and concise. It involves an orderly presentation of the results of an investigation. A report usually includes data, data interpretation, conclusions and recommendations for remedial actions.

When study objectives are crystallized, before the actual study commences, thoughts about the report should begin. The embryonic mental concept of the report should grow in organization and content as the investigation progresses, each phase of the study satisfying a part of an objective and fulfilling a part of the report.

The report is the end result of all the efforts expended on the study and should signal the beginning of any indicated remedial actions. A poor report frequently negates a meticulous field program; a good report will often ensure the success of the project. Any report should be planned as carefully as the field operation. The report's style will depend upon its intended purpose and the audience to which it is directed. It may be a record of the findings only. It may be an exposition of existing causes and effects and projections to other considerations that reasonably may occur. It may be a prediction of conditions to come and recommendations for actions to be taken. The report should be considered a document that records all essential facts in a study that will help meet the needs of those concerned, such as technical agencies and representatives of varied vested interests who may be for or against the conclusions and recommendations, as well as the public.

Too often the message that an investigator could bring to defining a water pollution problem is lost in poor reporting. Basic facts become mired in technical explanation. Concise interpretative reporting supported by uncluttered pertinent graphic and tabular materials will offer the reader a sound comprehension of the findings of fact. Presenting information that is understandable and meaningful to scientists, engineers, administrators, and to the general public is a challenge to the water quality investigator in reporting the results of his investigations.

Outline

The first step in developing a report is to make an outline. The outline should be considered carefully and should include all necessary items in logical continuity. An outline is a structural skeleton on which a good report may be built. It must have a beginning, a middle, and an end.

A good outline will avoid any omissions of necessary materials and save much time in report writing. Outlines will vary with report objectives, however, most reports on water quality will contain the following major items:

1. Introduction
2. Summary
3. Conclusions
4. Recommendations
5. Predictions based on following the various recommendations presented.
6. Description of study area.
7. Water uses:
    (a) Municipal
    (b) Fish propagation
    (c) Recreation
    (d) Industrial water supplies
    (e) Navigation
    (f) Irrigation
    (g) Hydropower
8. Waste sources:
    (a) Municipal
    (b) Industrial

    (c) Agricultural
    (d) Other nonpoint

9. Effects of pollution on water quality and uses:
    (a) Bacterial pollution
    (b) Aquatic life
    (c) Oxygen demand and dissolved oxygen
    (d) Aesthetic considerations

10. Appendix

An explanation of the methods of study, a tabular presentation of water quality data collected, methods of analyzing samples and mathematical calculations all can be relegated to the report's appendix. Here they may be available to the technical report reader but, on the other hand, will not interfere with the understanding of the report by an administrator who may be responsible for assuming a lead role in the implementation of the report's recommendation.

Organization

The title, authors, and table of contents pose initial decisions for the report writer. Long titles should be avoided but must identify clearly the work accomplished. Acknowledgments of aid and assistance are placed usually near the front of the report following the table of contents. A good report reviewer spends a great deal of time on his critique and should be acknowledged.

The report's introduction should describe briefly the problem and its location, the study objectives, the inclusive dates of the investigation, the authority for the study and by whom the study was performed. It may relate briefly the methods used to conduct the study, but generally such description should be placed in the appendix, particularly when it is lengthly and includes those methods that are not understood as standard procedures within the profession.

The summary of a report should briefly and concisely relate how the study was accomplished and what was found in the investigation. The entire summary should be as brief as possible and yet contain the essentials of the findings of fact. Stringent review and editing always should be employed. The summary should contain those particular facts that will be used to formulate conclusions.

The report's conclusions should be concise, positive, lucid statements that can be made from an evaluation of summarized data and other observations and that enhance an understanding of the problem. The report's summary can be a basis for the formulation of the conclusions. The report's narrative and the data it contains must support the conclusions presented. Just as a dredge is a tool to sample a stream or lake bed, words are tools to convey thoughts. Great care should be exercised by the report writer to choose the right words in formulating the conclusions and recommendations. Often the summary, conclusions, and recommendations may be the only parts of the reports that are read by many of the report's audience. There is often a difference of opinion among report writers regarding the numbering of thoughts or paragraphs within the conclusions. From the standpoint of conciseness and adherence to a particular thought it may be helpful to number conclusions in consecutive order at least initially. After these have been edited and re-edited the numbers may be removed without harm to the text material.

The report's recommendations contain the words to stimulate the remedial actions to correct the problem that was the cause of instigating the study. These should be developed with great care and sound logic and preferably numbered in consecutive order. Just as the individual conclusions are supported by statements within the report's summary, each recommendation should be the result of a particular conclusion and each conclusion requiring remedial action should have its correlative recommendation. The summary, conclusions, and recommendations of a report are the building block for the presentation of a logical sequence of thought, the purpose of which is to solve a particular problem.

Predictions may or may not be within the investigation's objectives. They are of great value to the report's reading audience however to ascertain the water quality that may be expected when all recommendations are met, or when 50 percent or 30 percent of the recommendations are implemented. Similarly, such predictions would depict the environmental outlook if no action is taken as a result of the investigation. Predictions should logically follow the report's recommendations.

The area description section should include a general area location map, as well as a specific map of the study reach showing stations sampled, principal population centers, and principal waste sources. Insignificant streams, highways, railroads, towns that are not involved, symbols for types of land use and similar features that are not pertinent to the study or to the understanding by the reader of the report should not clutter the base maps. On the other hand, any geographical feature that is mentioned in the text should be shown on the map. If the study is complex, one map may include locations of point waste sources. Another map may indicate points for areas of water use, and yet a third might show locations of sampling stations.

The water uses and waste sources sections need little explanation. Each item should be discussed in sufficient detail to inform the reader of the essential information. Monetary benefits and damages associated with water uses or lack thereof should be noted where possible. Measured or computed waste loads to specific stream reaches should be ascribed to waste sources.

The effects of pollution on water quality and uses include the findings of fact and their analyses, interpretation, and discussion. This is the report's section that supports the conclusions and recommendations. This is a section that defines present water quality and may predict future quality and uses when recommended remedial measures are effected. It is here that explanation may be proffered to solidify continuity of presented fact or to clarify a statement. Other studies often are cited to substantiate the writer's findings or to show that other investigators have found similar or different phenomena under comparable circumstances. Citations from other works should be referenced properly.

Report Development

A report consists of a number of logical interrelated processes that begin with the planning of the study and end with the distribution of the report to the recipients. It is in the study planning phase that the report takes embryonic shape. Each phase of the process is of equal importance to each other phase in the project's success.

It is in the organization of data within the report that the ingenuity and imagination of the report writer will reap great rewards. Data first are arranged in tables. Lengthy detailed tables should be placed in the report's appendix. When placed in a narrative they detract from reading coherency. Easy-to-follow summary tables, prepared as a digest of the tabular data in the appendix, are helpful in the narrative to explain and substantiate discussions and conclusions. Graphs should be uncluttered, pertinent, and easy to follow. Broad lines to illustrate trends are preferred. As an artist develops a painting with broad brush and board strokes, the report's author should arrange his graphs to portray essential information and should use them sparingly only to underscore principal points.

In developing a report the who, what, why, when, where, and how questions must be answered at every opportunity. Is the water quality degraded? Where and to what extent does degradation take place? What is the cause? What particular components are affected? When did degradation occur? How can the problem be solved?

Definite assertions should be made and noncommittal language avoided. The specific phrase should be chosen rather than the general phrase, the definite over the vague, the concrete rather than the abstract. Qualifying words should be avoided whenever possible. These are the leeches that suck the blood of decisiveness and weaken actions on implementing remedial solutions.

Develop the report for the waterway. Do not say, "Table 1 shows the biological data collected at the 13 stations; Figure 6 shows the relationship between species diversity and Jones' slough; Station 4 shows the dissolved oxygen to be 1.60 mg/l." Instead state, "The dissolved oxygen in Jones' slough, one mile downstream from Jonesville, was 1 mg/l on August 14, 1972. An examination of bottom-associated organisms in this same stream reach indicated that only sludgeworms could tolerate the degraded water quality (Table 1)."

Any calculations used in the report should be checked and rechecked. Tabular data should be checked against bench cards and graphic displays should be checked against tabular data for accuracy. Errors are prone to occur in bibliographic citations also. When an article is being sent to a professional journal for publication, the journal's editorial style, the manner in which the references are cited, and the style of presenting references should be noted. Adherence to journal style will insure consistency and enhance the possibility of acceptance of the article for publication.

Within the water quality report, the biological, microbiological, chemical and engineering reports are segments of the whole; each should complement the other. The successful approach skillfully blends the findings of all disciplines into a cohesive, inclusive, and comprehensive discussion of the aquatic environmental conditions found and the measures necessary to enhance those conditions to a level acceptable for society's uses.

Revision

Revision is a part of writing. Few writers can produce acceptable copies on the first attempt. Even the professional writers write and rewrite, revise, and rearrange. Quite often the writer will discover serious flaws that require transposition in his arrangement of a completed draft. When this is the case much time and effort can be saved by using scissors to cut the manuscript to pieces and tape to fit the pieces together in a more logical order.

Reading the manuscript aloud is a necessary adjunct to good report preparation. It tends to accent the flaws in rhythm, as well as illogical approaches and conclusions. Often laying the manuscript aside for a few days will give the writer a new insight, a more objective approach, and a more critical appraisal of words and structures. It is no sign of weakness or defeat when a manuscript is in need of major revision. This is a common occurrence in all writing.

Special effort should be made to avoid redundant and tautological phrases. Often a report writer will become carried away and may repeat an entire paragraph with slightly different sentence structure but without the addition of substantive thought. Such repetition should be avoided like a disease and should be deleted during the revision process.

Care should be exercised to choose the proper words to express the idea. A number of words and expressions commonly are misused in water quality reports. Examples of these are:

Upstream from should be used rather than *upstream of* or *above*. Similarly, *downstream from* should be used rather than *downstream of* or *below*. "From" denotes direction; "above" or "below" connote a vertical comparison rather than the more horizontal reality associated with comparing two stations on a stream.

Data takes a plural verb always, *datum* is the singular.

Affect is a verb meaning to influence; *effect* is most commonly a noun meaning result. When used as a verb, *effect* means to bring about or accomplish.

That is a defining or restrictive pronoun; *which* is non-defining or non-restrictive.

Farther is a word relating to distance; *further* is a time or quantity word.

Owing to means because of; *due to* means the result of. *Owing to* may be used at the beginning of a sentence in the sense of because of; *due to* should not be so used; *due to* should commonly be preceded by some form of the verb *to be*.

Its is the possessive pronoun; *it's* is the contraction for *it is*.
Rather than saying *owing to the fact that*, use *because*.
Rather than saying *different than*, use *different from*.
Rather than saying *in order to*, use *to*.

Review and Final Report

When a report is submitted and is accepted by a reviewer, both the writer and reviewer assume certain specific obligations. The writer should submit his report for review only after completing his own revision and editing and after striving for the best in manuscript preparation as his talents permit. Further, he should inform the reviewer of the report's purpose and its expected audience if these facts have not been made clear in the report itself. Preferably, a minimum of two manuscript copies should be sent to each reviewer so that the reviewer may retain one for his files and return the other with comments in the report's margin if that is his desire.

A proper review, on the other hand, entails consideration of the technical message in a report, as well as the manner in which the message is presented. A review can be directed toward editorial comments only but rarely can a technical review disregard the editorial aspects. Good grammar and technical competency usually are inseparable. A technical reviewer reads a document for clarity, technical accuracy, and to determine whether a dual meaning is present in the sentence or paragraph. The reviewer is obligated to consider the purpose that the report is designed to fulfill; to be constructive, thorough and helpful with comments; to be certain of his own accuracy in suggesting changes; to base comments on the technical level and interest of the report's intended audience; to avoid sarcasm, argument or destruction of the writer's style for the sake of expression in the reviewer's words; and to appreciate always that the purpose of the review is to help the report's writer produce a better report.

Following consideration of all the review comments, the report is ready for final assembly. Graphs, pictures, and summary tables should be rechecked for consistency and subheads and to make sure that they follow the narrative reference to them. The appendix is the place for detailed procedures and tables. These too should be consistent in format, understandability, and sequential arrangement.

Finally, an appropriate cover should be designed for the report. The report cover serves as a wrapping to the package and may influence the recipient's opinion of the report or even his desire to examine its contents in more detail. An imaginative cover design will pay dividends. Usually the most effective designs are simple, direct, and representative of the report's subject matter.

14

Slime Nuisances

WHEN associated with water quality, the word slime is a collective designation to describe the iron and sulfur bacteria and the organisms that may live in association with them or the particulate matter that may be entrapped by the slime growths. The organisms are characterized by their ability to transform or deposit significant amounts of iron or sulfur and may be filamentous or single celled, aerobic or anaerobic.

Upon the introduction of waste nutritive materials into watercourses, biological slimes may develop to the extent that visible masses appear. Such masses may be woolly coatings on submersed objects or tufts and strands sometimes 15 inches or more long streaming in the current from the point of attachment. They vary in color from milky white in fresh new growth to dull grey-white, brown or rusty-red depending on age, nutrition, and the type and amount of solids they entrap from the passing water.

Numerous problems arise from the presence of slime growths in waterways. Slimes may foul commercial fishing nets rendering them ineffective, interfere with fish hatching by coating fish eggs, and smother aquatic fauna that serve as food for fish. Biological slimes and the materials they entrap, such as plant fibers, wood chips and debris, blanket the stream bed and destroy the homes of clean water-associated organisms. They may cause filling and plugging of wells and water distribution systems. Sulfate-reducing bacteria may cause rusty water and pitting of pipes. These organisms may also cause odor, taste, frothing, color, and turbid water. They destroy the recreational potential of the water and cause an aesthetically unpleasant waterway. To the public, slimes are an obvious visible sign of water pollution.

Although organic food usually is abundant where slime growths occur, the food supply of iron and sulfur bacteria may be wholly or partly inorganic and they may extract it from a low concentration in inflowing waters. Temperature, light, pH, and oxygen supply affect these organisms' growth. Under different environmental conditions some bacteria may appear either as iron or as sulfur bacteria.

Plate 24. Slimes form waving masses in polluted streams that destroy the habitat for animals and the waterway's aesthetics.

Most bacteria respond directly to the introduction of organic materials into a watercourse. They are the major factor in the self-purification process occurring in most natural waters. Slime growths in natural waters function similarly to the bacteria. Substantial biochemical oxygen demand reductions and high purification rates have been observed in many shallow turbulent streams in which slime growths were the major force in the self-purification process.

Iron Bacteria

Iron bacteria are typically aerobic organisms, widely distributed in nature, and commonly observed in most habitats. Generally they are considered fouling organisms and not agents of corrosion but they may contribute indirectly to the latter. They obtain energy from the oxidation of ferrous iron to ferric iron, and in the process ferric hydrate is precipitated. The iron withdrawn from the water is deposited on or in the secretions of the organisms. When water is passed through an iron pipe, the iron may be obtained from the pipe itself. The amount of ferric hydrate deposited is very large in comparison with the enclosed cell. The bacteria are able to produce a large amount of brown slime and may impart a reddish color and an unpleasant odor to the water. Springs often have a reddish-brown deposit produced by the activity of these bacteria and stagnant marshes may produce a reddish scum as a result of their activity. As early as the middle of the 19th century, iron bacteria in potable water supplies were reported to be the positive organisms of taste and odor problems. The flocculent deposit has been observed to accumulate to a depth of 2-feet throughout several miles of drainage ditch under natural conditions.

The identification of nuisance iron bacteria usually has been made on the basis of microscopic examination. The bacteria readily can be settled or filtered from water. They occur in such masses either in bulked activated sludge, naturally in lakes, rivers, or streams, or in cooling towers that the material may be examined directly without concentration. Identification usually is through comparison of microscopic specimens with plates in standard reference texts.

Sewage Fungus

One of the iron bacteria, *Sphaerotilus natans* is associated closely with sewage and certain industrial wastes. It has been implicated in the bulking of activated sludge and has created problems in papermaking wet felts. Its appearance in streams as a dominant organism has been associated with effluents from beet sugar, paper, rayon, glue, flour mills, textile bleach, by-product coke, dairy wastes, and spent sulphite liquors. Like other iron bacteria, the organism has the ability to extract nutrients from large volumes of flowing water at extremely low waste concentrations. It has been reported to grow in sulphite waste liquor dilutions of one in 700,000. In some polluted European rivers, estimates have been made that range as high as 300 tons wet weight per day of drifting *Sphaerotilus* passing a given point.

The secondary effects of biological slimes in streams may be as serious as the initial pollution. A growth of *Sphaerotilus* acts as a net and entraps silt, sand, wood fibers, small wood chips and other debris. It offers shelter and support for other organisms such as bacteria, protozoa, nematodes, rotifers, and occasionally midge larvae. There is a high degree of secondary pollution resulting from the decomposition of this mass at its ultimate resting place.

The most important food requirements necessary for heavy *Sphaerotilus* growths appear to be sugars and organic nitrogen. Further, there appears to be competition between filamentous and planktonic algae and *Sphaerotilus* for the available phosphorus. Under conditions of active growth, the detached and floating slime materials may be assumed to be equivalent to the new material being formed.

Sulfur Bacteria

Some of the sulfur bacteria are encountered occasionally in water, particularly in water containing sulfide or elemental sulfur. One of the typical sulfur bacteria, *Thiobacillus*, may bring large amounts of iron into solution under conditions favorable for its development. It is an aerobic bacterium that has the capacity to oxidize sulfur and, by its production of sulfuric acid, has contributed to the destruction of concrete sewers and the acid corrosion of metals.

Sulfate-reducing bacteria are of importance in water distribution systems because they produce sulfide, which is dissolved in the water and makes it objectionable by reason of odor, the presence of suspended black particles, and the corrosive effect of the sulfide on steel and other metals.

Plate 25. Massive slime accumulation on commercial fisherman's net

Identification of nuisance sulfur bacteria usually has been made on the basis of microscopic examination of the suspected material. Samples of slimes, suspended in water, scrappings from exposed surfaces, or sediments may be examined directly. Green sulfur bacteria may occur commonly in waters high in hydrogen sulfide. Sulfur globules are seldom if ever deposited within the cell. Purple sulfur bacteria occur also in waters containing hydrogen sulfide but the cells are stuffed with sulfur globules and often are so intensively pigmented that the individual cells appear red. In addition there are the colorless filamentous sulfur bacteria that occur in waters where both oxygen and hydrogen sulfide are present and colorless nonfilamentous sulfur bacteria that usually are associated with decaying algae.

The true sulfate-reducing bacteria are microorganisms that use sulfate as an oxidizing agent for respiration instead of oxygen that is used by the aerobic bacteria. They produce massive concentrations of hydrogen sulfide as a respiratory end product, which properly distinguishes them from the many bacteria that form small amounts of hydrogen sulfide during the decomposition process. Natural waters invariably contain the sulfate ion although not in high concentrations. The growth of aerobic bacteria multiplies as food is supplied by organic polluting materials. In this process these bacteria reduce the oxygen tension to values at which the sulfate-reducing bacteria and other anaerobes can develop. In addition, the toxic effects of some of the metabolic products of the aerobic bacteria kill many of the aerobes and enhance the effects of pollution. The hydrogen sulfide formed by the sulfate-reducing bacteria is a substrate for the development of colorful sulfide-oxidizing bacteria and massive growths of these may lead to red waters.

A massive number of environmental phenomena are associated with the development of sulfate-reducing bacteria. Examples of these include disagreeable odors, blackening of nearby paint work, tarnishing of copper or silver domestic materials, and the blackening of stones, sands and muds on waterway bottoms.

The anaerobic corrosion by pitting of iron and steel and sometimes zinc and the corrosion of concrete and stone principally by sulfuric acid formed from the hydrogen sulfide are some examples of the adverse economic effects of the sulfate-reducing bacteria. On the opposite side of the environmental ledger, these and associated bacteria have been credited with the formation of elemental sulfur in the world's major sulfur deposits, with the release of oil from shale, and further in the genesis of oil deposits themselves.

15

Plant Nuisances

VEGETATIONAL problems in water may derive from the masses of floating, attached, and rooted plants. These growths become problems only when conditions of existence promote excessive standing crops that interfere with a water use. The purpose of this presentation is to examine the assets, liabilities, interrelationships, and growth stimulators for aquatic plants. More appropriate control of excessive production can often be implemented through an understanding of these phenomena.

Assets

Aquatic plants, like most other living matter, are not all bad or all good. Their assets are many and their liabilities are most often associated with their degree of concentration.

Plants are a basic and extremely important component of the aquatic ecosystem. As the basis of the food chain they are the bread of life for the aquatic grazing animals. Such animals range in complexity from the thousands of different kinds of mostly microscopic zooplankton to ducks and diving birds and fur-bearing animals as well. Serving not only as food in themselves, aquatic plants act as the high rise apartment homes for a myriad of different small animals that are a vital link in the aquatic food web that culminates in a fish population.

Aquatic plant apartment homes provide protection from predators to their inhabitants. All aquatic vegetation areas will support many times the animal population that may be found in non-vegetational areas within the same ecosystem. Plants are collectors for fish and the fishing potential is increased in areas adjacent to standing crops of vascular plants. Many fish use these areas as foraging grounds and dine contentedly upon the apartment dwelling inhabitants of the vascular plant community.

These same plants serve as the substrate for the spawn of many organisms including snails and fish such as the yellow perch. Just forty years ago, Rudolfs and Heukelekian noted the effects of sunlight and green organisms on the reaeration of streams and found that the dissolved oxygen in water containing large quantities of algae could be decreased from supersaturation to 17 percent saturation by placing the water in darkness, and could also be increased to 282 percent saturation by subjecting it to diffused light (Rudolfs and Heukelekian, 1931). If the darkness experiments had been extended over a longer time period, these early researchers would have no doubt found the oxygen saturation decreasing into an oxygen deficit. By adding oxygen during the process of photosynthesis, plants decrease the problems associated with decomposition of organic materials that may be present.

Plants tend to purify their surrounding water by other means. Certain algal and vascular plant populations have been found to possess a bactericidal quality that reduces the concentration of coliform bacteria and presumably pathogenic bacteria that would otherwise be associated with the specific environment.

In photosynthesis, aquatic plants use carbon dioxide and liberate dissolved and free gaseous oxygen at times of supersaturation. Since energy is required in the form of light, photosynthesis is limited to the photic zone where light is sufficient to facilitate this process. During respiration and decomposition, animals and plants consume dissolved oxygen and liberate carbon dioxide at all depths where they occur.

Computations of net photosynthetic oxygen production for several lakes yield values lying mostly between 12 to 57 pounds of oxygen per acre per day. A year-around study under completely natural conditions in western Lake Erie showed winter yields of about 11 pounds per acre per day and summer maxima of about 85 pounds per acre per day. The annual oxygen curve closely followed the solar radiation curve. Net oxygen photosynthesis in two Alaskan lakes ranged from 3.4 to 4.0 pounds per acre per day (Goldman, 1960).

Liabilities

When aquatic plants are stimulated in some manner to the production of a standing crop so abundant that it interferes with a water use, plant nuisances develop. It is at this point where citizens, whose normal use of the water has been restricted by an abundant plant growth, demand remedial measures and control of the nuisance. Plant nuisances may curtail or eliminate bathing, boating, water skiing and sometimes fishing; perpetrate psychosomatic illness in man by emitting vile stenches; impart tastes and odors to water supplies, shorten filter runs or otherwise hamper industrial and municipal water treatment; impair areas of picturesque beauty; reduce or restrict resort trade; lower water front property values; interfere with the manufacture of a product in industry such as paper; on occasion become toxic to certain warm blooded animals that ingest the water; reduce the use potential of irrigation waters through evapo-transpiration; foul irrigation siphon tubes and trash racks; and cause skin rashes and hayfever-like symptoms in man.

Most algal problems occur when growth conditions permit the formation of a "bloom." A bloom is an unusually large number of cells (usually one or a few species) per unit of surface water, which can be seen as a green, blue-green, brown or even brilliant red discoloration of the water.

Algae are found in every non-toxic aquatic habitat. Constituting a primary source of food for fish and other aquatic animals, they may be free-floating and free-swimming, or attached to the bottom substratum.

Excessive algal growths are troublesome in many ways. When present in great numbers, algae may: give an unsightly blue-green or green appearance to the water, form a massive floating scum that obstructs navigation or impairs water use, in decay produce noxious odors that drive people from the area, remove dissolved oxygen from the water when decomposing and kill aquatic life as a result, foul fish harvesting equipment and water intake devices, reduce the carrying capacity of water distribution systems, and destroy bathing and other water use areas. *Stigeoclonium*, *Oedogonium*, *Ulothrix*, and *Cladophora* have been problems in irrigation systems where they have restricted flow in the canals, and fouled pumps and tubes. *Cladophora* has been a problem of great concern in Lakes Ontario, Erie, and Michigan where abundant growths have become detached through wave and wind action to be washed upon a beach where they decompose to make the area uninhabitable.

Blue-green algae have been severe nuisance problems, especially to those engaged in water oriented recreation in most eutrophic lakes. *Chara*, a branched erect alga that becomes encrusted with calcareous deposits giving the plant a rough surface has become a problem in many high alkalinity lakes and ponds. Often *Chara* becomes abundant following the destruction of aquatic vascular plants. Should the lake or pond bed be composed of a peat-type material, *Chara* can become detached from its mooring and bring substantial quantities of bottom with it when it rolls to the surface in 9-inch thick rafts that obstruct navigation, destroy aquatic aesthetics, and emit vile odors. The author has witnessed dead tree stumps, with root systems that measure 20-feet in diameter, embedded in these floating *Chara* rafts.

In highly enriched streams, green algal streamers that may exceed 50-feet in length provide an excellent substrate for black fly larvae, midge larvae, and other nuisance animals.

Conditions of Existence

Dispersal of water plants is accomplished by water transport, migratory birds, air transport of algae, and by domestic and other animals. Seeds may remain viable after passing through the digestive tract of animals, and seeds and other means of propagation may be transported by animals externally. Water plants usually produce an abundance of seeds but propagation through vegetative means is a most effective method of distribution. A small broken portion of a healthy plant may soon reestablish itself, when, in settling out of the water, it roots again on a suitable substrate. Most aquatic plants are perennials and are well adapted to withstand heavy cropping by animals.

Plant populations will develop in the aquatic environment wherever conditions are suitable. Plants have been found growing at a depth of 500 feet in Lake Tahoe (Frantz and Cordone, 1967). Providing the aquatic environment is non-toxic, light intensity and nutrients are the principal controlling factors for planktonic growths. Temperature is an important factor with some of the nuisance forms such as blue-green algae. Light intensity, water temperature, wave action, flow velocity, nutrient abundance, water depth and type of substrate, all interact to govern the establishment of weed beds or weed sparsity. Both bottom sediments, as well as the water contribute nutrients to the plants (Martin et al., 1969; McRoy and Barsdate, 1967). Sediments supply inorganic nutrients through the plants relatively weak root system.

Many submersed plants, as well as algae, continue active in winter, providing ice and snow cover are not sufficiently opaque to reduce light penetration so that growth is impeded. Once established in an area, rooted aquatic plants exhibit a high degree of persistence and efficiency of propagation. Some reproduce only by means of seeds formed in insect pollinated flowers borne at or above the water's surface. Others propagate by buds, tubers, roots and node fragments in addition to producing viable seeds. Factors that limit growth include insufficient light, insufficient nutrients, physical instability because of water level fluctuation and current and wave action, an unsuitable bottom stratum, and competition by other plants and animals. Considering that the physical properties of the environment are favorable, the nutrients become the prime stimulators and controllers of aquatic plant production. The most important required nutrients are carbon, nitrogen, phosphorus, certain trace elements, organic growth factors, and, in the case of diatoms, silica.

Limiting Factors

Of the required nutrients, one will become limiting for future growth if other physical and chemical features of the aquatic environment are suitable. The term, "limiting" is one that has caused much misunderstanding among many of those who attempt to evaluate limiting factors. Something is always limiting to the further growth of a biological population. That which is limiting at one level of production may not limit at another. The term "limiting", when associated with eutrophication and its control should refer to that substance which when added will stimulate a biological population to increase and become restrictive, or more detrimental, to a given water use.

Hutchinson (1957) states, "Of all elements present in living organisms, phosphorus is likely to be the most important ecologically, because the ratio of phosphorus to other elements in organisms tends to be greater than the ratio in primary sources of the biological elements. A deficiency of phosphorus, is therefore, more likely to limit productivity." Research over the succeeding years has not produced evidence that would discredit this basic observation.

Basic sources of nutrients to waterways are (1) tributary streams carrying land runoff and domestic and industrial wastes, (2) the biological and chemical interchange between bottom sediments and superimposed water, and (3) precipitation from the atmosphere. Tributary streams have been reported to carry 21 pounds of phosphorus per square mile of drainage area in sparsely settled forested areas, 225 pounds of phosphorus per square mile of drainage area in agricultural areas, and more than 6,000 pounds in densely populated urban areas (Keup, 1968).

The question is sometimes asked, how much algae can be grown from a given amount of phosphorus? Allen (1955) found that the maximum that could be grown in the laboratory on sewage, an excellent growth media for algae, was 1 to 2 g/l (dry weight) and in the field in sewage oxidation ponds the maximum was 0.5 g/l. Thus, assuming optimal growth conditions and maximum phosphate utilization, the maximum algal crop that could be grown from 1 pound of phosphorus would be 1,000 pounds of wet algae under laboratory conditions or 250 pounds wet algae under field conditions. Considering a cellular phosphorus content of 0.7 percent in algae, 1 pound of phosphorus could be distributed among 1,450 pounds of algae on a wet weight basis. A considered judgment suggests that to prevent biological nuisances, total phosphorus should not exceed 100 μg/l P at any point within the flowing stream, nor should 50 μg/l be exceeded where waters enter a lake, reservoir, or other standing water body. To enhance the quality of this Nation's lakes, reservoirs and estuaries, we must reduce to the ultimate phosphates, and all other nutrients where feasible, from all controllable sources.

With suitable environmental conditions, plants will develop and avail themselves of the space and available nutrients. With the application of chemicals to a segment of the aquatic environment, it is possible to change the predominant growth from vascular plants to planktonic algae or attached algae and visa versa almost at will.

There are over 17,000 species of algae and fresh water forms which are grouped into blue-green algae, green algae, yellow-green algae, golden-brown algae and diatoms, red algae, euglenoids and dinoflagellates. Some of these are capable of producing physiologically active metabolites that may function as toxins, growth inhibitors, or growth stimulators to themselves or to associated algae. Some algae are born to self-destruct. After a growth period when extracellular products have accumulated, it is thought that these act as deterrents and that the plant, in a sense, manufactures its own algicide (Prescott, 1960). The extracellular substances (possibly of a toxic nature) have prevented the growth of certain other species, and thereby the plant that begins its development first in a body of water quickly assumes a dominance, depending upon its inherent cell division rate. With auto-destruction comes a reduction in the inhibitor, thus another species or group of species is permitted to develop.

Natural waters contain these active agents that are secreted and excreted by fresh-water algae. The toxicity of these agents to other algae and bacteria and to fish varies constantly and is not well understood in the aquatic environment. It has been postulated that algae secrete not just one substance but several, some antibiotic, others stimulating. The amount secreted and the net result of the secretions would be determined by the prevalence of one group of substances over the others. Thus sequences of algal blooms may be expected to occur under conditions of a nutrient supply in excess of critical values.

16

Animal Nuisances

WHEN aquatic animals become abundant they can become pests and nuisances to man because of their biting habits and their sheer mass of numbers. Some aquatic animals serve as intermediate hosts for parasites that may attack man directly and some serve as vectors of diseases that affect the health and welfare of man.

Sponges

Sponges in irrigation systems can cause hydraulic problems when growing in association with other aquatic animals and plants. This undesirable effect is compounded by the favorable substrate they create for a wide variety of other aquatic pest organisms that form a community of life in association with the sponges.

The fresh-water *Bryozoa* are a group of organisms referred to as pipe moss. They attach to logs, rocks, and other submersed objects usually where the light is relatively dim. They have been found in a number of irrigation systems growing in profusion on concrete, canal linings, submerged inlet screens, louvers, trash racks, and on the inside of pipes. The individual animal is microscopic. It secretes an individual protective layer around the body wall and many of these individual animals grow in close association to produce a connected highly branched antler-like colony.

Midges

Midges have created nuisance problems around the shores of a number of lakes, ponds, and swampy areas. The females of some genera have mouth parts adapted for blood sucking and bite most actively at dusk or in the shade during daytime. These minute insects are annoying pests and are variously called midges, gnats, punkies, and "no-see-ums." Their bites can cause considerable irritation and itching and even fever. Human individuals differ in their susceptibility to the bites of these insects.

The eggs of the biting midges are deposited on plants or vegetable matter in shallow water. In about three days they produce a 12-segmented larva that leads an aquatic existence for 6 to 12 months after which it passes into a pupal stage from which the adult fly emerges.

Other non-biting type midges have proven to be nuisances around lakes because of the great numbers of the adults. These hoards of adult midges have been known to get into children's eyes and noses, turn houses black with insects, and literally stall traffic along lake shore roads in the evening because of the inability of drivers to see. Also because of this abundant food supply, spiders increase in numbers where midges are prevalent and their webs drape the trees, bushes, and buildings and create an additional nuisance.

Midge larvae feed almost exclusively on algae that have settled to the bottom muds and thus are found in great numbers in organically enriched lakes that are high in algal production. Under favorable conditions, the larval midge population may exceed 1,000 larvae per square foot of lake or pond bottom. Since emergence of the adult midges takes place from the entire surface of the lake at approximately the same time, nuisances result from the mass of adult numbers. The adults swarm during the late afternoon or early evening in their mating flight. The swarm has been described as being composed almost entirely of males, beginning with a few individuals, and increasing in proportion as others join its ranks. Like a single unit, the mass moves forward for a short distance, then drifts back with the wind, then moves forward again and so on and on in endless repetition. There is much weaving in and out and up and down among the individuals within the mass. This produces a somewhat regular rise and fall of the whole mass in the vertical plane.

Estimates have been made of the adult emergence from bloodworm larvae for Clear Lake, California. The total seasonal production from a 44 square mile lake area was estimated at slightly over 700 billion gnats or 356 tons of organisms. One night's emergence was estimated at 3½ billion gnats. This was from an area where sampling indicated a population of 1,000 bloodworms per square foot of bottom. When this mass of minute organisms becomes concentrated along one shore because of the wind drift, the results can approach catastrophic proportions.

Mayflies and Caddisflies

Mayflies and caddisflies are among those organisms that water pollution biologists refer to as clean-water-associated. Because of biologic or climatic phenomena or both these organisms may cause nuisances when the adults emerge in great numbers.

The immature forms of these organisms can be found in nearly all types of unpolluted aquatic habitats. Most species spend about one year as an aquatic organism but there are those that spend two years in the immature stage. Unusual hoards of mayflies may leave the water on the first suitable day after adverse weather conditions. The adults are fragile insects that die within a few hours and when they occur in hoards their dead bodies may clog ventilator ducts and sewers and may also cause temporary traffic difficulties.

Fremling (1960) reports on mayfly problems caused by the large burrowing mayfly, *Hexagenia bilineata* (Say), in some areas of the Mississippi River. Upon emerging ". . . the mayflies rest on terrestrial objects during the day, and under their weight, tree limbs become pendulous and even break. Residents of summer homes along the river find their houses covered and their yards littered by the insects. A constant rustle is heard as the insects are disturbed and fly up from their resting places. The dead insects and their cast nymphal exuviae form foul-smelling drifts where they are washed up along the shore . . . crews of the towboats which transport freight on the Upper Mississippi River find mayflies to be a navigational hazard . . . Visibility is greatly reduced by the mass of insects in the searchlight beams. The crushed insects render the decks, ladders, and equipment of the boats slippery and dangerous. The towboats must of necessity be completely hosed off with water after each encounter with a large swarm of mayflies."

A number of years ago the dead bodies of mayflies were piled as high as four feet on some of the bridges crossing the Mississippi River and snowplows were used to clear a path for traffic. The adult mayflies are not equipped with mouth parts and therefore take no food during this stage of their life history. The adults' sole purpose is to complete the reproductive cycle.

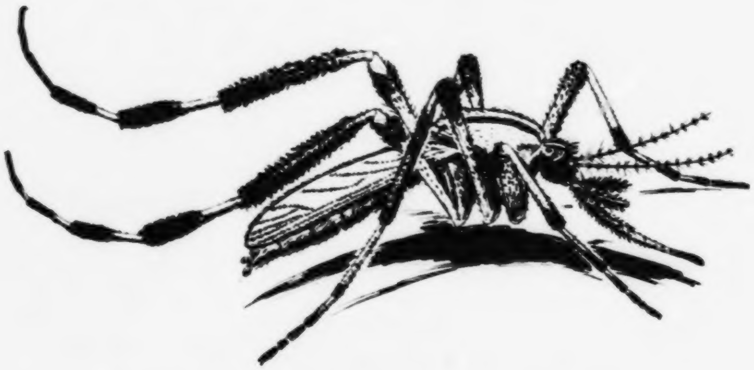


Plate 26. Mosquito [*Psorophora ciliata* (Fabricius)] one of the largest of Illinois mosquitoes.

Likewise, adult caddisflies have created nuisances and health problems in certain areas. They swarm around the city lights during most of the summer and often blanket store windows. Masses of the insects dart into the faces of people, flutter under their eyeglasses, and under open-necked clothing. The minute setae that are dislodged from the wings and bodies of the caddisflies can cause swelling and soreness around the

eyes of hypersensitive individuals. The individual may exhibit a typical hayfever-like symptom as a result. Again, spider webs become pendulous with captured caddisflies making the riverside homes unsightly. Both caddisflies and mayflies have been reported by a number of authors to be a cause of allergic distress.

Mosquitoes

In 1947 Ross estimated the Nation's annual "mosquito bill" at $100 million because of mosquito-borne diseases, and close to $50 million for screening, pest control programs, and depressed real estate values. Mosquitoes cause an economic loss both as nuisances and as disease carriers.

Mosquitoes in the nuisance group inflict financial loss in various ways. In some sections they restrict the vacation season by inflicting painful bites, with subsequent loss of patronage to resort establishments. They attack domestic animals and fowl and, when bites are inflicted in large numbers, cause loss of weight and ill health. It has been established that 500 mosquitoes will draw about $\frac{1}{20}$ of a pint of blood per day from an exposed animal. (Ross, 1947). Sometimes mosquitoes become so abundant that they interfere with or stop work by man with a consequent loss of labor and accomplishments. Mosquitoes are among the worst nuisances of the out-of-doors and prevent enjoyment of recreational facilities by many people seeking exericse and relaxation.

While a fertilized female mosquito usually cannot produce fertile eggs without ingesting blood, at least three species are able to deposit the first batch of eggs without a blood meal. The eggs of two common genera are deposited in water while those of *Aedes* are deposited in shaded localities on ground subject to intermittent flooding. The number of eggs laid at one time varies between 100 and 400. The eggs develop into larvae, which are voracious feeders and molt four times before developing into a pupa. The pupal stage is a non-feeding transformation part of the life history from which the fully developed insect emerges. The male mosquito does not suck blood but feeds upon the nectar of flowers and the juices of fruit.

Water areas with little wave action, an abundant cover in the form of aquatic vegetation, an abundant food supply in the form of humus or other organic matters, and floating particles of microorganisms are a preferred habitat for mosquito egg deposition and for the development of mosquito larvae. The mosquito production of the lake or reservoir appears to be directly proportional to the amount of intersection line between plants and the water surface. Situations with an abundance of intersection line provide mosquito larvae with food and protection from natural enemies and also furnish the adult mosquitoes with an ideal environment for egg deposition. The intersection value of various aquatic plants varies according to the percentage of vegetation cover occurring at the water surface.

Mosquitoes serve as vectors for the three principal arthropod-borne viruses in the United States. Birds serve as natural hosts and man as an accidental host, but clinical disease in man is produced by all three viruses. These are western equine, eastern equine and St. Louis encephalitis. Western equine and St. Louis encephalitis occur primarily in the 22 western States, whereas eastern equine encephalitis occurs primarily in the Atlantic and Gulf Coast States.

Mosquitoes serve as the intermediate host in the transmission of parasitic diseases such as malaria and filariasis. Filarial worms, *Wuchereria bancrofti*, are slender nematode parasites that invade the circulatory and lymphatic systems, muscles, connective tissues or serous cavities of the vertebrates. The organism is carried by 41 species of mosquitoes and produces elephantiasis, which is characterized by massive glandular swelling. It is a disease that occurs commonly among the people of Puerto Rico.

Other Insects

Black flies, *Simulium* spp. are a pest to fishermen and woodsmen and may incapacitate both man and animals. Large numbers of cattle, horses, and other domestic animals have perished from the depravation of these flies in Europe and America. Their bite may produce an ulcer-like sore that is due to salivary toxins. In susceptible individuals there may be marked inflammation, local swelling, and general incapacity. As carriers of human diseases, black flies are not serious in this country although many persons may get severe dermatitis from their bites.

The adult fly deposits eggs on vegetation or other solid substrate just under the surface of swift water, especially where the current is broken. Overwintering sometimes occurs in the egg stage. The eggs hatch below the water surface to produce larvae which attach themselves to a solid submerged substrate. The larval stage may last from two to six weeks. During the last stage of development the larvae construct silken cocoons in which the insects develop into pupae, a growth stage preceding development and emergence of the adult. The cocoons are firmly cemented to the substrate and create roughened surfaces on canal linings. These extensive areas of pupal encasements increase resistence to water flow in canals. The cases are persistent and often require mechanical removal from the canal linings.

Deer flies and horse flies are of medical importance not only because they are aggressive blood-sucking pests but also because certain species transmit diseases to man and animals. As mechanical vectors they may carry pathogenic organisms on their mouth parts and bodies. *Chrysops discalis*, the western deer fly, can transfer tularemia to both man and animal and remains infective for at least two weeks. Occasionally anthrax germs also are carried on the beaks of horse flies and deer flies between the diseased and healthy animals and sometimes to man. Anthrax is highly infective to all classes of mammals, including man.

The stable fly, *Stomoxys calcitrans* resembles a housefly in appearance. Its mouth parts are adapted for piercing and for sucking blood and it is a vicious biter. The fly sucks blood for two to five minutes or longer until its abdomen becomes distended. In some of the Tennessee Valley Authority impoundments, extensive breeding areas have been created for this organism by the aquatic vegetation and algae that concentrate on the water surface in dense mats of decomposing plants. In some waterways this pest breeds prolifically in floatage created by the bodies of dead mayflies and aquatic vegetation. In the past, extensive recreational areas have had to be closed in the Tennessee area because of this pest. The flies feed repeatedly on animals since at least three blood meals are required for egg production. Cattle and horses have been known to die because of frequent and heavy attacks from fly bites. The flies' habit of leaving one animal to resume feeding upon another makes the stable fly an ideal mechanical carrier of disease-producing agents.

Leeches

Leeches are found in warm protective shallow water where there is little wave action and where plants, stones, and debris offer concealment. They are chiefly nocturnal in their activities and remain hidden under stones and vegetation in daylight. The majority of leeches are found in shallow water up to a depth of approximately six feet. They require substrates to which they can adhere and consequently are rare on pure mud and clay bottoms. Some species persist in intermittent pools by burrowing into the bottom mud where they construct a small mucous-lined cell in which they live. Leeches are dormant in winter and bury themselves in the upper part of the bottom materials just beneath the frost line.

Although several genera take blood from man, only two genera are true blood-sucking leeches. These require only an occasional full meal of blood because specimens have been kept for more than two years without feeding. The leech of greatest concern to bathers is *Macrobdella decora*, the northern blood-sucking leech. It is a swamp animal principally and normally inhabits the shallows in the vicinity of the shoreline where land and water meet. It may be found concealed under stones and logs where, when well fed, it rests quietly or, when hungry, lies and waits for frogs or warm-blooded animals. Like all other blood suckers, this leech attaches to the host with the caudal sucker and explores with the anterior end until a suitable spot is located where the skin is thin. The oral sucker is then attached tightly and three painless incisions are made by a back-and-forth rotary motion of the jaws. Sufficient blood is taken to distend the stomachs so that the leech may be five times as heavy as it was when it began feeding. When the leech has filled its digestive tract it leaves the host voluntarily but the incisions keep on bleeding for a variable time because of the persistence of the salivary anticoagulant, hirudin, which the leech injects into the incision and which causes a more or less intense prolonged itching. If the leech is permitted to complete its meal, this substance is largely or entirely withdrawn from the wound but if the meal is curtailed, it acts as an irritant.

Any disturbance of the water, such as is caused by a wading animal, attracts the leeches partly because of the mechanical disturbance that stimulates the tactile organs and partly because of the animal emanations that stimulate the organ's chemical sense. Thus, leeches are attracted by bathers and tend to congregate and remain about the docks and stones of the bathing area. They are strong and rapid swimmers and

Plate 27. Interim Canal, California, with Asiatic clams completely covering canal bed.

can invade a particular area from other sections of the lake or pond. Leeches are most active at maximal water temperatures and their period of greatest prevalence in the bathing area corresponds with that of maximal water temperature in late summer.

Macrobdella decora may be identified by its bright striking color pattern, large size, and soft slimy very contractual body. It has a medium longitudinal role of 20 to 22 orange or light red spots. A similarly arranged series of small black spots on each side close to the margins, and a rich orange ventral surface that sometimes is plain but usually is spotted with black. Five pairs of eyes are arranged in a regular arch near the anterior dorsal margin. The last two are especially difficult to see in pigmented specimens. The body is elongated, flattened, smooth, very soft, slimy and very contractual. The maximum extended length is seven to eight inches, whereas the usual extended length is four to six inches.

Other Organisms

The Asiatic clam, *Corbicula fluminea* has caused significant problems of operation and maintenance in irrigation and other canals in several areas. These organisms have contributed to silt accumulation in two ways: by continually moving the top of the bottom sediments and covering any material that settled out, thus holding the settled material on the bottom of the canal, and by removing suspended solids from the

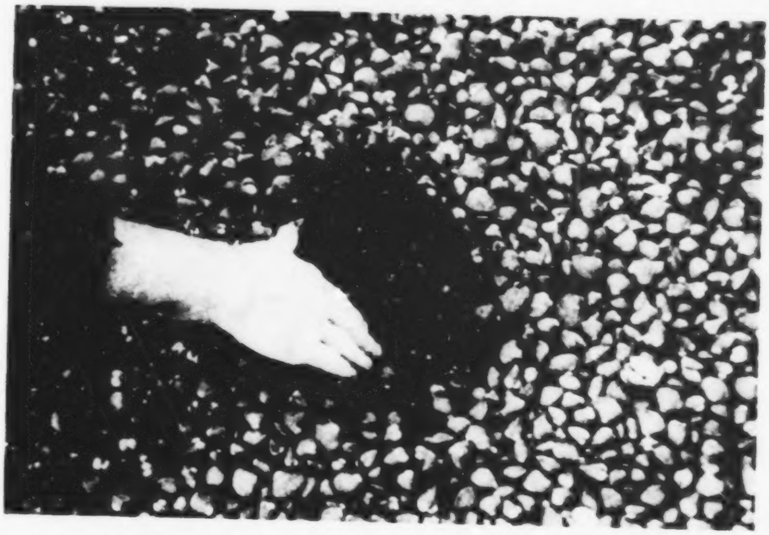


Plate 28. Closeup of undisturbed canal bed, Interim Canal, California, with multitudes of Asiatic clams.

water through their process of filtration and depositing the solids on the canal bed combined with a proteinaceous slime that does not go back into suspension readily. In certain canals, the density of these organisms has been found to exceed 5,500 per square foot. The bed of a canal system can become heavily graveled with clams.

The Asiatic clam probably will become a nuisance to water treatment plant operators and has become a nuisance to the sand and gravel industry in portions of the Tennessee Valley. Clams present in the river gravel are introduced into the aggregate. Mechanical separation is almost impossible. When the clams are poured with the concrete aggregate, the live clams move toward the surface, which leaves a void. Moving concrete sometimes results.

A variety of organisms including snails, bloodworms, sow bugs, and water fleas have been reported as pests in the distribution systems of domestic water supplies. The dates for most of the infestations were several years ago and public awareness and better operation and maintenance of the water treatment plants have reduced greatly the potential for such organisms to be found in the present-day treatment system.

17

Other Health Related Aquatic Animals and Plants

Swimmer's Itch

CORT (1928) first demonstrated that the larvae of certain trematode worms of birds and mammals can penetrate the skin of man and produce a dermatitis characterized by papular eruptions. "Swimmer's itch," schistosome dermatitis, or "water rash" has attracted increasing attention since 1928, particularly in the lake regions of the North-Central United States where tourist trade has been affected.

The cercariae causing swimmer's itch are free-swimming, colorless, and about 0.7 mm in length. With proper illumination they are just visible to the unaided eye as they swim rapidly in an irregular manner or hang suspended in water. The adults are parasitic in the hepatic, portal, and mesenteric veins of birds and mammals. The fertilized female migrates to the smaller intestinal veins and deposits eggs that work their way through the intestinal wall into the lumen, from which they are passed with the feces. Each egg contains an embryo that, upon hatching, develops into a ciliated free-swimming organism termed a miracidium. If a suitable snail is located, the miracidium penetrates into its soft tissues, and a further type of development takes place in which a sporocyst and then cercariae are produced. Following this period of development, the cercariae emerge from the snail host and swim about in search of the proper vertebrate host to penetrate where they can develop to maturity in the blood vessels to complete the life cycle.

The cycle is interrupted accidentally by the occasional penetration of cercariae into the epithelial layer of the skin of bathers, and swimmer's itch results. Following such penetration, the cercariae are soon destroyed by unsuitable human body fluids and their bodies remain at the penetration site to cause acute inflammatory reactions. Apparently the cercariae do not penetrate completely until the bather has emerged from the water; however, a few minutes after emergence the victim experiences a tingling sensation in exposed parts of the body. Soon, minute red spots can be seen at the points where the organisms have penetrated the skin. The tingling sensation may then disappear, and it may be a number of hours before a distinct itching is felt, and the minute spots enlarge to form discrete red elevations of the skin $\frac{1}{16}$ to $\frac{1}{4}$ inch in diameter. Occasionally the elevations become pustular. The degree of discomfort and bodily reaction resulting from infestation varies with the sensitivity of the individual and the degree of infestation. With particularly sensitive persons, considerable pain, fever, and severe itching may occur along with noticeable swelling of the affected areas; in others the discomfort may be only minor and transitory, and some bathers appear immune to infestation. The skin elevations typi-

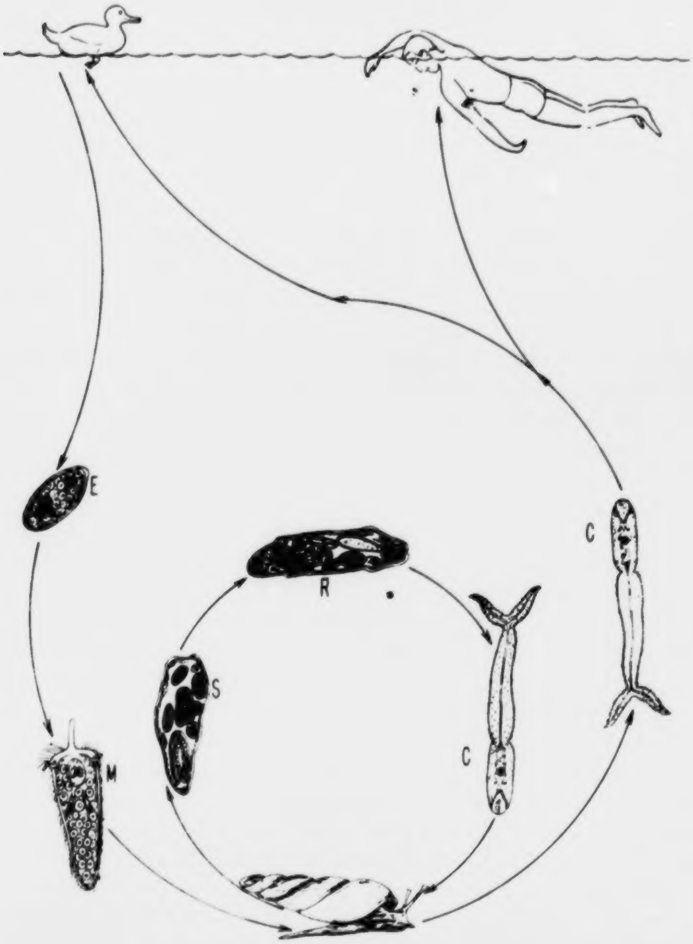


Figure 17. Life cycle of swimmer's itch cercariae. E. Egg; M. Miracidium; S. Sporocyst; R. Redia; and C. Cercariae.

cally disappear within a week, but the redness may persist for some time longer.

Cercariae may live in the water from 24 to 60 hours or more after emerging from the snail host (Brackett, 1941). It is probably safe to assume that under natural conditions the life span is only 24 hours or less, and in wind-agitated water it may be considerably shorter. The types of cercariae capable of producing swimmer's itch typically emerge from the snail host quite regularly at a definite and more or less restricted period each day. The majority of forms emerge about 4:30 a.m., and one type emerges at about 9:30 p.m. Because cercariae probably survive at least 24 hours under conditions in nature, it appears during an outbreak that the causative organisms may be present in water at all times of the day. The typical emergent activity of the cercariae may be influenced to some extent by factors existing in the water.

There is evidence that submersed aquatic plants promote swimmer's itch. Some of the species of snails capable of harboring the causative organism live in and upon stands of submersed aquatic plants that often grow adjacent to or in the vicinity of bathing areas. Also, at least two species of cercariae attach themselves to objects and may cling to such vegetation. Under these circumstances, the removal of the submersed vegetation will usually eliminate infections to bathers by the parasite.

Cercariae emerge in greatest numbers during the warmest weather. Infected snails kept at low temperatures cease to shed cercariae; however, if these snails are brought into a warmer environment such as a room-temperature laboratory bench, cercariae emerge suddenly in large numbers regardless of light conditions. Cercariae are also attracted by light and swim actively in the direction of the greatest light intensity. These characteristics facilitate the identification of the organism in the laboratory. Although active swimming by the cercariae may be limited to 50 feet or less, it is thought that they may be carried distances of 1/4 mile or more by the movement of surface water. In many places bathers are troubled only when there is an inshore wind of not too great intensity, and only those who bathe in the shallow water close to shore are affected. Those who swim in the deeper water farther from shore are scarcely bothered even though they swim directly over an infected bed of snails.

Cort (1950) listed 18 species of schistosome cercariae, excluding those that develop to maturity in man in other areas of the world, that have been reported to cause dermatitis. Brackett (1941) states that "one of the most striking and clear-cut features of schistosome dermatitis outbreaks is the fact that probably over 90 percent of the more severe outbreaks are caused by *Cercaria stagnicolae* in varieties of the snail *Stagni-*

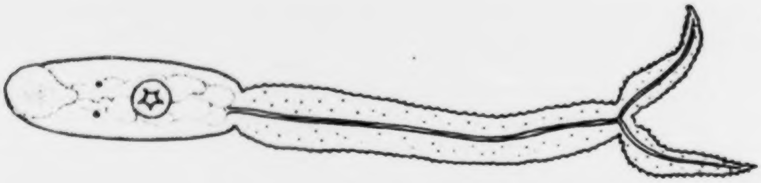


Figure 18. Cercaria of the type causing swimmer's itch.

cola emarginata." The relationship between this snail and the most severe outbreaks of swimmer's itch is promoted by: (1) clean, sandy beaches ideal for swimming and preferred by the snail; (2) peak populations of the snail host that develop in sandy-bottomed lakes of glacial origin; (3) the greatest development of adult snails that do not die off until toward the end of the bathing season; and (4) the cycle of cercarial infection so timed that the greatest numbers of cercariae emerge during the hot weather in the middle of the summer when the greatest amount of bathing is done.

Plate 29. Snails known to harbor swimmer's itch cercariae.

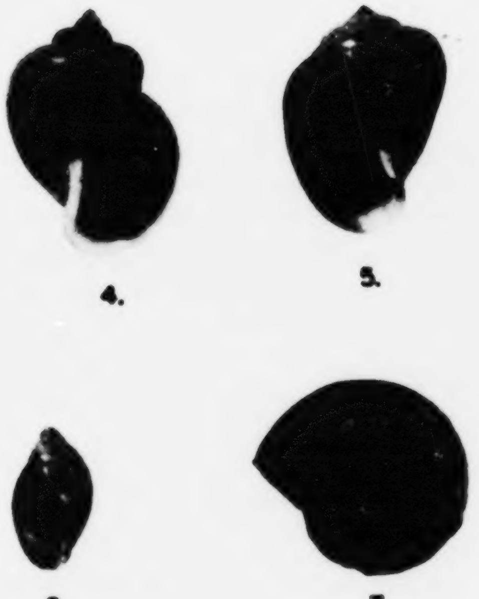


Plate 30. Snails known to harbor swimmer's itch cercariae.

*U.S.N.M.** *No.*	*Snail*	*Collector*	*Location*
1. 284448	*Lymnaea (Lymnaea) stagnalis* (Linnaeus).	Bryant Walker	Detroit, Mich.
2. 569286	*Lymnaea (Radix) auricularia* (Linnaeus)	F. C. Baker	Greenhouse, Lincoln Park, Chicago, Ill.
3. 30255	*Lymnaea (Stagnicola) palustris elodes* (Say).	L. H. Streng	Grand Rapids, Mich.
4. 30252	*Lymnaea (Stagnicola) emarginata* (Say).	L. H. Streng	Lake Houghton, Mich.
5. 251214	*Physa parkeri* Currier.	H. B. Baker	Douglas Lake, Mich.
6. 334392	*Physa ampullacea* Gould	W. Westgate	Klamath Falls, Oreg.
7. 432259	*Gyraulus parvus* (Say).	J. P. E. Morrison	Boulder Junction, Wis.

* United States National Museum.

In the Lake States the seasonal cycle of the parasite in relation to the life cycle of the intermediate host snail determines the seasonal variation in the dermatitis infections. The first case on the bathing beaches usually occurs in late June or early July when the snails infected in the fall begin to give off cercariae in appreciable numbers. Exact dates may vary somewhat with the season and with water temperature. During July, the peak of cercarial production is reached, and the infections reach their highest intensities. Production is especially influenced by hot spells that speed up the development of the cercariae and increase the numbers that escape. Later in the summer the dermatitis cases lessen, chiefly because of the death of infected snails; in many places there is a complete cessation before the end of the swimming season. When the adult snails die early, the dermatitis season is shortened since there is practically no infection of juvenile snails during the summer.

Schistosome dermatitis is widespread. As summarized by Cort (1950), it has been reported from the United States, Asia, Japan, Australia, Wales, France, Switzerland, Cuba, Mexico, and Canada. In the United States, schistosome dermatitis has caused greatest problems in the North Central lake region. In addition to Wisconsin, Minnesota, and Michigan, schistosome dermatitis has been reported from North Dakota, Illinois, Nebraska, Texas, Florida, Washington, Oregon, Nevada, Oklahoma, California, Connecticut, Rhode Island, New York, and Iowa.

The pathology and symptomatology of schistosome dermatitis is described by Belding (1942): "The resistance of man, an abnormal host, to these cercariae explains the severe reaction. Its nature indicates that the cercariae are walled off by the host and destroyed in the epithelial layers of the skin. Penetration of the skin occurs when the film of water evaporates. The cercariae adhere with the ventral suckers and enter in about 5 minutes through the action of their anterior spines and lytic secretions, either between or through the pores. After 29 hours no cercariae remain but the reaction persists around the burrows. They evoke an acute inflammatory response with edema, early infiltration of neutrophils and lymphocytes, and later invasion of eosinophils. As the water evaporates a prickling sensation is followed by the rapid development of urticarial wheals, which subside in about half an hour leaving a few minute macules. After some hours severe itching, edema and the transformation of the macules into papules and occasional pustules occur, reaching maximal intensity in 2 to 3 days. The papular and sometimes hemorrhagic rash heals in a week or more, but may be complicated by scratching and secondary infection. Individuals vary in susceptibility and show slight or severe reactions."

Schistosomiasis, the Blood Fluke Disease of Man

Schistosomiasis caused by *Schistosoma mansoni*, is widely distributed throughout Puerto Rico and is an important health problem there. It has been estimated that up to 12 percent of the population are infected (Anon. 1946). The 2 types of environments responsible are the streams and pools used for bathing and other domestic purposes, and the irrigation systems. The intermediate host, *Australorbis glabratus*, prefers the quiet waters of stream pools, irrigation ditches, and reservoirs. The habits of the people play an all important role in the spread of the infection. The natives commonly use the snail-infested waters for bathing and washing and there is excessive human pollution of the water and diversion of untreated sewage into streams.

In the human, cercarial penetration may give rise to a more or less intense local reaction. The immature worms then find their way to the veins and are carried to the lungs; this requires 2 or 3 weeks. From the lungs the developing worms find their way to the liver lobules. Nausea, vomiting, headache, and abdominal pain may be the systemic complaints. After becoming nearly mature in the liver the worms migrate against the blood stream to the small veins in the mesenteric venules draining the colon and the terminal section of the small intestine. The adults produce virtually no pathologic process in the mesenteric venules. They feed on serum and cells but not so gluttonously as to create any noticeable effect. Egg deposition is initiated within an average of 10 weeks following infection. Abdominal pain, tenesmus, dysentery, blood-flecked stools, and remittent fever are results of the intestinal egg deposition process. The eggs are equipped with a lateral spine that aids in tissue penetration. Severe liver damage is typical. The liver becomes involved and enlarged because of the drift of the eggs back through the portal blood stream into the liver. Enlargement of the liver results in abscesses around infiltrated eggs. Tissue damage in unarrested and progressive cases is severe, and in all moderately heavy infections would be enough alone to cause death. The liver becomes a gigantic mass of scar tissue. Accompanying symptoms are daily fever, extreme weakness, diarrhea, loss of appetite and weight, emaciation, and, in untreated cases, death from exhaustion.

The destruction of snails theoretically offers the best method of control of these parasites. The practical application of such control measures, however, is far from satisfactory.

Fish Parasites Important to Man

The broad tapeworm, *Diphyllobothrium latum* (Linnaeus, 1758) Luhe, 1910, is a parasite of man, dog, cat, fox and hog. It is acquired through the eating of raw or improperly cooked fish. The parasite is prevalent in regions of the northern temperate zones where fish from fresh-water lakes form an important part of the human diet. It was first observed in the United States in 1858 and is known to be present in northern Minnesota, Southeastern Manatoba, the Lake Nipigon District of Ontario, and the Portage Lake district of Michigan's upper peninsula. The worm recently has been reported from Florida.

The life history of *Diphyllobothrium latum* involves two intermediate hosts—copepods, and fresh-water fish. The parasite's eggs are discharged with the feces from the host organism. The eggs are hatched in 9 to 12 days after reaching water and the ciliated embryo can swim for several days until it is ingested by a suitable species of copepods. The copepod is, in turn, eaten by small fish where the larvae undergo further development. The small fish may be eaten by a larger specimen. Man and other animals are infected by eating raw fish. The types of infected fish can be northern pike, walleye, sauger, and yellow perch. In the intestine of man, the parasitic worm reaches maturity in about three weeks. The length of the adult worm ranges from 3 to 30 feet and its width is about 10 to 12 mm. Infestation can cause anemia and loss of weight. The parasitic infestation may be spread through the marketing of infected fish caught from an endemic area. Freezing at −10°C for 24 hours, thorough cooking for at least 10 minutes at 50°C, and proper drying and pickling of the fish will kill the larvae.

Swimming-associated Amoebic Meningoencephalitis

Amoebic meningoencephalitis is a recently recognized disease of man that has exhibited extremely high fatality. Epidemiologically, the disease appears to be acquired following swimming in fresh or brackish waters. Of the 45 swimming-associated cases that have been reported to date, 22 have occurred in the United States. Eighteen of these have been reported from the State of Virginia, all of which were fatal to the swimmers.

The disease is caused by an amoeba that is indistinguishable in appearance from a free-living amoeba, *Naegleria gruber*, commonly found in sewage effluents, surface waters, and soils. The amoebic's pathogenic strains, however, exhibit physiological differences from those of the wild strains that are encountered commonly in swimming pools and other areas. Clinical and autopsy findings, together with experimental data obtained from laboratory animals, have led to the belief that the disease is a result of the invasion of amoeba into the cranial area from the upper nasal region. Apparently the amoeba reached the upper nasal region when infested water is accidentally forced into it during the process of swimming or diving.

Much remains yet to be learned about this organism. Methods for identifying pathogenic and non-pathogenic forms need to be developed. Additional studies on the organism's pathogenicity are needed. The chemical nature of the cytotoxic substance produced by the pathogenic strains of amoeba must be investigated.

Health-associated Algae

Waters containing dense populations of algae, when ingested, have been responsible for mammalian, avarian, and fish deaths, as well as outbreaks of human gastroenteritis. The causative algae belong to the blue-green group and are of the genera *Microcystis*, *Aphanizomenon*, *Anabaena*, *Nodularia*, *Coelosphaerium*, and *Gloeotrichia*.

Animal intoxication by phytoplankton has been known since 1878. In most recorded cases, the attacks occurred after the animals had drunk from lakes or ponds containing heavy algal growths. Such growths occurred usually during successive days of hot and humid weather and often when deaths of animals occur a wind has been reported blowing, and causes the concentration of algae in the lee-shore areas.

The syndrome of symptoms, described by Fitch et al. (1934), exhibited by guinea pigs from the feeding or from the inoculation intraperitoneally of a fatal dose of toxic algae was: (1) restlessness, (2) urination, (3) defecation, (4) deep breathing, (5) weakness in the hindquarters, (6) sneezing, (7) coughing, (8) salivation, (9) lachrymation, and (10) clonic spasms and death.

Although as little as 0.02 ml of a toxic algal solution injected into mice intraperitoneally may kill a 20-gram individual in an hour, the danger to man is not necessarily great. Gorham (1964) reviewed the literature on toxic algae as a public health hazard. He concluded that the fish and livestock poisons produced by waterblooms were nuisances and economic hazards rather than public health hazards. It was estimated that the oral minimum lethal dose of decomposing toxic *Microcystis* bloom for a 150-pound man would be 1 to 2 quarts of thick paint-like algal suspension. Gorham stated that this amount would not be ingested voluntarily. However, in the case of an accident such a quantity might be ingested involuntarily.

Seventeen case histories of human gastrointestinal disorders associated with algae generally within the United States and Canada are recorded in the literature. The manifestations of toxicity included headaches, nausea, gastrointestinal upsets and in some cases vomiting and diarrhea (Mackenthun and Ingram, 1967). Human respiratory disorders have been associated with algae by 14 authors since 1916. The manifestations of toxicity here included burning in the throat, nostrils and eyes, sneezing and coughing. Human skin disorders associated with algae have been recorded in 10 articles since 1937. The gastrointestinal and skin disorders generally have been associated with fresh-water algae whereas the algae causing human respiratory disorders were almost equally divided between the fresh water and the marine forms.

18

Key to Commonly Encountered Algae

AN artificial key is presented for some of the algal genera commonly encountered in recreational waters. Because of a preponderance of genera associated with the fresh-water environment, other English-language publications useful in supplying descriptive details and pictures for identification are listed. These include Forest (1954), Palmer (1959), Patrick and Reimer (1966), Prescott (1951), Prescott (1954), Smith (1950), Taft (1961), and Tiffany and Britton (1952).

AN ARTIFICIAL KEY TO SOME AQUATIC NUISANCE ALGAE *

To use the key, the specimen must be observed under a microscope to determine its pertinent characteristics. These characteristics are compared against the first couplet in the key. Choosing the one that best fits the specimen, one must proceed to the designated couplet following and repeat the operation until a genus is reached.

1. Plant consisting of a thread, strand, ribbon, or membrane composed of cells; frequently visible to the unaided eye 2
1. Plants of microscopic cells that are isolated or in irregular spherical, or microscopic clusters; cells not grouped into threads 25
2. Heterocysts present. (Heterocysts are specialized cells, larger, clearer, and thicker walled than the regular cells in a filament; they separate from other algal cells permitting portions of chains to grow into completely new individuals) 3
2. Heterocysts absent 8
3. Threads gradually narrowed to a point at one end, appearing as radii, in a gelatinous bead or mass 4
3. Threads same width throughout 5
4. Spore (an asexual reproductive structure) present, adjacent to the terminal heterocyst ...... GLOEOTRICHIA
4. No spore present ...... RIVULARIA

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* Modified from Palmer, C. M. (1959).

5. Branching absent, heterocysts contained within the filament, threads encased in a gelatinous bead or mass.....NOSTOC
5. Threads not encased in a definite gelatinous mass............ 6
6. Heterocysts and vegetative cells shorter than the thread width ....NODULARIA
6. Heterocysts and vegetative cells not shorter than the thread width 7
7. Heterocysts rounded ....ANABAENA
7. Heterocysts cylindric ....................APHANIZOMENON
8. Branching absent 9
8. Branching (including "false" branching) present.............20
9. Cell pigments distributed throughout the protoplasm.......10
9. Cell pigments limited to plastids (bodies within plant cell that contain photosynthetic pigments)......................12

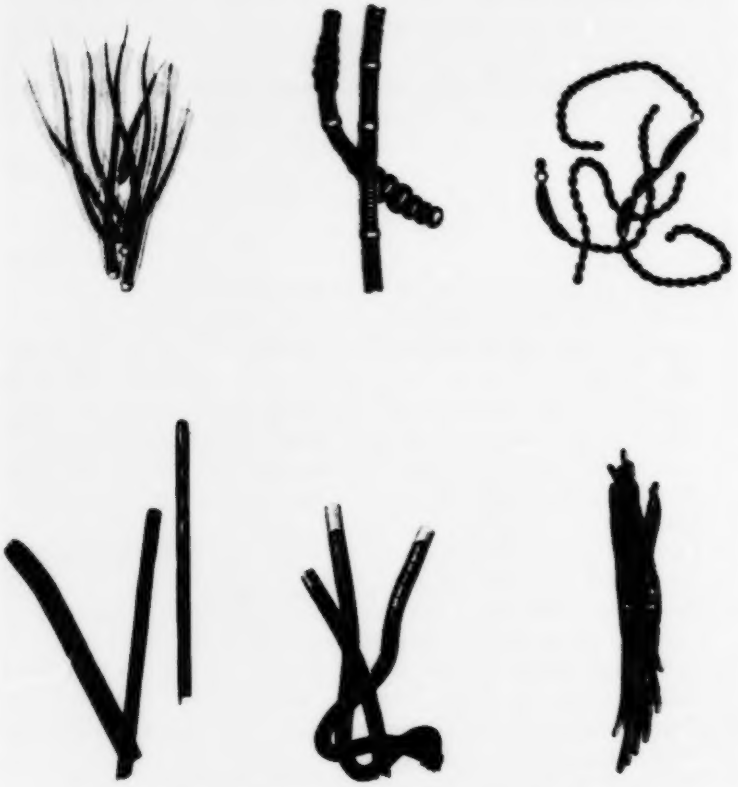

Plate 31. Nuisance Algae. Top row, left to right, *Rivularia, Nodularia, Anabaena,* Bottom row, left to right, *Oscillatoria, Lyngbya, Aphanizomenon.*

10. Threads long, not forming a spiral, one thread per sheath; sheath or gelatinous matrix present 11

10. No sheath or gelatinous matrix apparent ...... OSCILLATORIA

11. Sheath distinct; no gelatinous matrix between threads .. LYNGBYA

11. Sheath indistinct or absent; threads interwoven with gelatinous matrix between .... PHORMIDIUM

12. Cells forming a thread or ribbon, cells separating readily into discs or short cylinders, their circular face showing radial markings .... CYCLOTELLA, STEPHANODISCUS

12. Cells either not separating readily, or if so, no circular end wall with radial markings 13

13. Cells in a ribbon, attached side by side or by their corners 14

13. Cells in a thread, attached end to end 15

14. Numerous regularly spaced markings in the cell wall .... FRAGILARIA

14. Numerous markings in the cell wall absent .... SCENEDESMUS

15. Plastid in the form of a spiral band .... SPIROGYRA

15. Plastid not a spiral band 16

16. Plastids two per cell, cells with a smooth outer wall .. ZYGNEMA

16. Plastids either one or more than two per cell 17

17. Plastids close to the cell wall, occasional cells with one to several transverse wall lines near one end ...... OEDOGONIUM

17. Occasional terminal transverse wall lines not present 18

18. Cells with one plastid that has a smooth surface, cells with flat ends .... ULOTHRIX

18. Cells with several plastids or with one modular plastid 19

19. Iodine test for starch positive, one plastid per cell, threads when broken separating irregularly or between cells .... RHIZOCLONIUM

19. Iodine test for starch negative, several plastids per cell, side walls of cells straight, not bulging. A pattern of fine lines or dots present in the wall but often indistinct .. MELOSIRA

20. Branches reconnected, forming a distinct net .. HYDRODICTYON

20. Branches not forming a distinct net 21

21. Each cell in a conical sheath open at the broad end . DINOBRYON

21. No conical sheath around each cell 22

22. Branching commonly single or in pairs, cells green, threads not surrounded by a gelatinous mass, light and dense dark cells intermingled in the thread .... PITHOPHORA

22. Most of cells essentially alike in density 23

23. Branches few in number, and short, colorless .. RHIZOCLONIUM

23. Branches numerous and green 24

24. Terminal attenuation (a continuous decrease in width of a filament, often to a point or thin hair) gradual involving two or more cells .... STIGEOCLONIUM

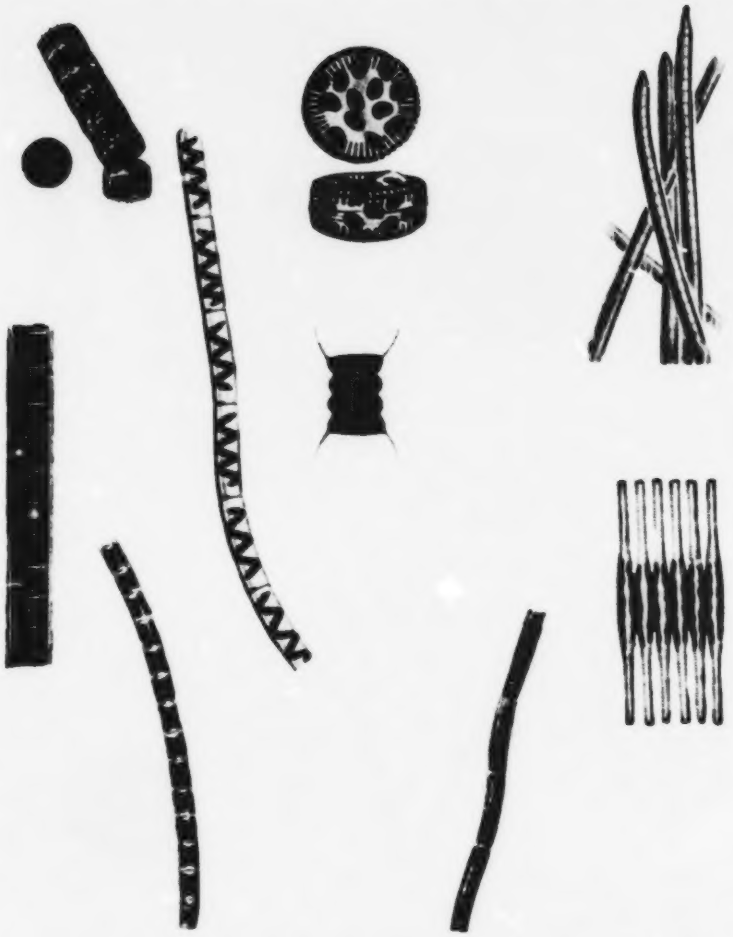

Plate 32. Nuisance Algae. Top row, left to right, *Stephanodiscus, Cyclotella, Phormidium;* center row, left to right, *Zygnema, Spirogyra, Scenedesmus;* bottom row, left to right, *Ulothrix, Oedogonium, Fragilaria.*

24. Terminal attenuation absent or abrupt, involving only one cell ....CLADOPHORA
25. Cells in colonies generally of a definite form or arrangement....26
25. Cells isolated, in pairs or in loose, irregular aggregates........31
26. Cells without transverse rows of markings, cells arranged as a layer one-cell thick....................................27
26. Cells without transverse rows of markings, cell cluster more than one-cell thick and not a flat plate......................28

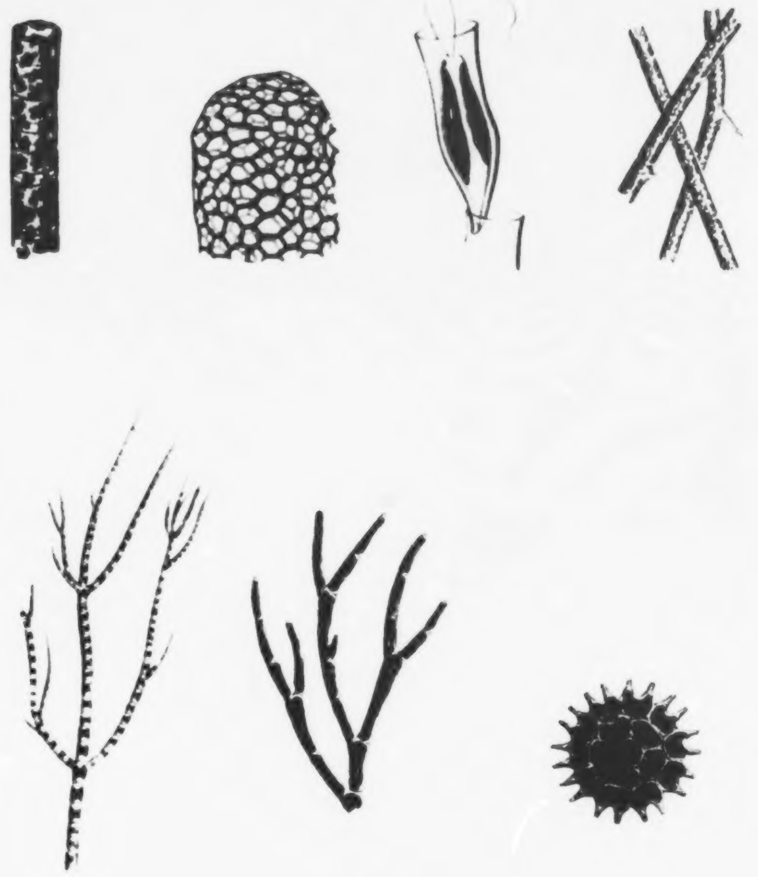

Plate 33. Nuisance Algae. Top row, left to right, *Melosira, Hydrodictyon, Dinobryon, Rhizoclonium;* bottom row, left to right, *Stigeoclonium, Cladophora, Pediastrum.*

27. Cells elongate, united side by side in one or two rows .... SCENEDESMUS

27. Cells about as long as wide, not immersed in colorless matrix, cells angular with spines, projections, or incisions .... PEDIASTRUM

28. Cells sharp-pointed at both ends; often curved like a bow, loosely arranged or twisted together .... ANKISTRODESMUS

28. Cells not sharp-pointed at both ends; not bent as a bow 29

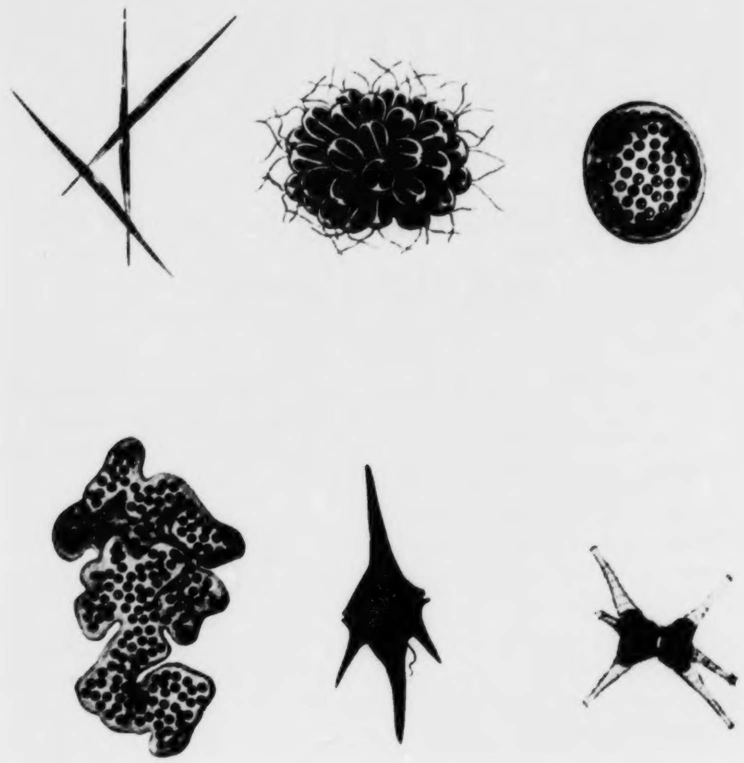

Plate 34. Nuisance Algae. Top row, left to right, *Ankistrodesmus, Synura, Coelosphaerium;* bottom row, left to right, *Microcystis, Ceratium, Staurastrum.*

29. Flagella present, cells touching one another in a dense colony, cells arranged radially, facing outward, plastids brown .... SYNURA

29. Flagella absent 30

30. Cells not elongate, often spherical, plastids absent, pigment throughout, cells equidistant from center of colony .... COELOSPHAERIUM

30. Cells irregularly distributed in the colony, not equidistant from the center, cells rounded .... MICROCYSTIS

31. Cells with an abrupt median transverse groove or incision; cells brown, flagella present .... armored flagellates (e.g. CERATIUM)

31. Cells with an abrupt median transverse groove or incision; cells green, no flagella .... Desmid (e.g. STAURASTRUM)

19

Key to Commonly Encountered Vascular Plants

SPECIFIC identification of aquatic plants is possible sometimes only through the examination of minute plant parts by specialists. A key is presented that will aid the non-systematists in the identification of the common plant groups. It is divided as follows:

A. Plants floating on water surface.
B. Plants submersed beneath water surface.
C. Plants erect and emersed; rooted to the substratum and extending upward out of the water.

Other manuals supplying descriptive comments and pictures as an aid to more specific identification include: Eyles and Robertson (1944), Fassett (1960), Martin et al. (1957), Mason (1957), Morgan (1930), and Muenscher (1944).

AN ARTIFICIAL KEY TO SOME COMMON AQUATIC PLANTS

To use the key, one must select the proper group and read the description in the first couplet. The description that best fits the unknown specimen will indicate either the plant group or genus to which the specimen belongs or an additional couplet, in which case the process is repeated until the description for a particular plant or genus best fits the unidentified specimen.

PLANTS FLOATING ON WATER SURFACE

1. A lobed or regularly forked plant body, usually small in size, roots usually suspended free in the water, with no connection to lake bottom; capable of drifting.............. 2

The duckweed group includes the smallest of the aquatic flowering plants. They have neither true leaves nor stems, but the floating green plant body, usually possessing tiny roots that penetrate the water, looks like a leaf and is often so-called. Duckweed floats on the surface of pools, marshes, and ponds, and may grow abundantly in enriched streams; from such streams it may enter standing water areas and become a nuisance as it is held by plant and other obstructions. It may become sufficiently dense to prohibit sunlight from penetrating the water, and thus algae and other aquatic plants are killed. It physically obstructs water use, creates an unsightly condition, and upon decomposition produces odors. It is difficult to kill because of the waxy sheen to the plant body and the characteristic "layering" of one plant upon another. Provided the plant mass is not held in place by obstructions, the wind or currents aid greatly in preventing proliferation of the plant mass.

Occasionally the layman may confuse duckweed with algae. Close observation or the examination of any object removed from the water surface will clearly show the clinging bright green plant bodies to be much larger than nonfilamentous microscopic algae.

1. Floating-leafed plants with leaves attached to the bottom by a bare unbranched stem of varying length................ 6
2. Plants consisting of forked or cross-shaped, long-stalked segments, floating below the surface; often many entangle to form clumps....Star Duckweed, **LEMNA TRISCULA** Linnaeus
2. Plants rounded, not stalked................................ 3
3. Plants with roots.. 4
3. Plants without roots....................................... 5
4. Plants red on the lower surface, each joint with two or more roots....Big Duckweed, **SPIRODELA POLYRHIZA** (Linnaeus)
4. Plants green on the lower surface, each joint with one root ....Duckweed, **LEMNA**
5. Plants globular, pea green, the size of a pinhead........ Watermeal, **WOLFFIA**
5. Plants thin, sickle-shaped or elongated..............Duckweed, **WOLFFIELLA**
6. Stem attached to middle of leaf........................... 7
6 Stem attached at the summit of a deep notch in the leaf........ 8
7. Leaves oval, not more than 3 inches wide, with supple stem attached to the middle of the leaf..................Watershield, **BRASENIA SCHREBERI** Gmelin
7. Circular leaf with a long, fairly rigid stem attached to the middle of the leaf, leaves 6 inches or more wide sometimes supported by the stem above the water level....American Lotus, **NELUMBO**

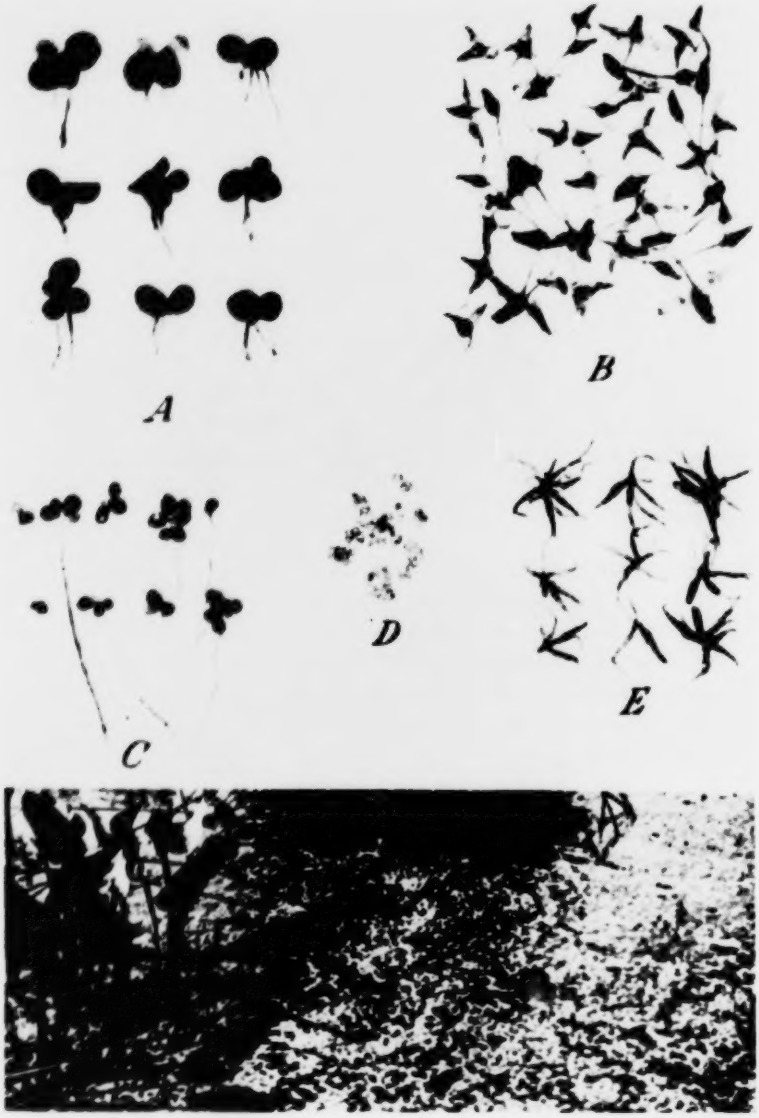

Plate 35. Duckweeds (Lemnaceae. A. Big duckweed [*Spirodela polyrhiza* (Linnaeus)]; B. Star duckweed (*Lemna trisulca* Linnaeus); C. Duckweed (*Lemna*); D. Watermeal (*Wolffia*); E. *Wolffiella*; F. Big duckweed on a Maryland pond.

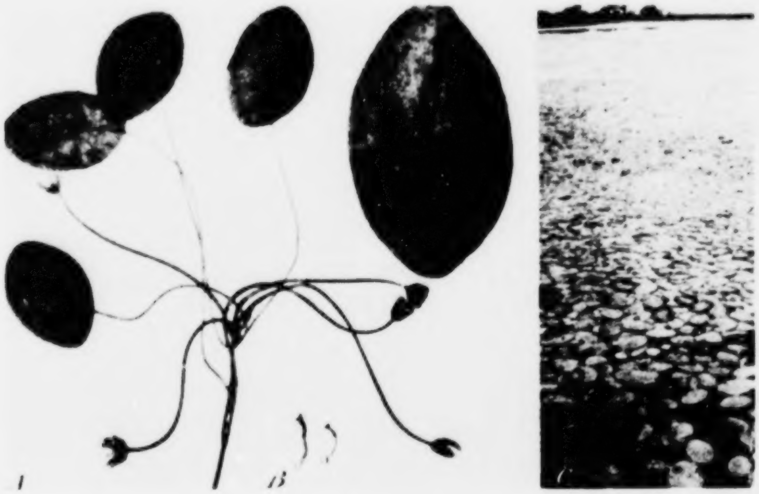

Plate 36. Watershield (*Brasenia schreberi Gmelin*) x ⅜.

8. Circular or heart-shaped leaf with the veins radiating from the mid-rib nearly to the margin without forking; floating yellow flowers....................Yellow Pond Lily, NUPHAR
8. Circular leaf with much-forked veins radiating to the margin, white, or pink floating flowers..........White Water Lily, NYMPHAEA

PLANTS SUBMERSED BENEATH WATER SURFACE

1. Plant body made up of stems bearing whorled, smooth, brittle branches, easily snapped with a slight pressure; plants with a musky odor, no roots, often with a limy encrustation Green Algae, Muskgrass, CHARA

Plate 37. American Lotus (*Nelumbo*).

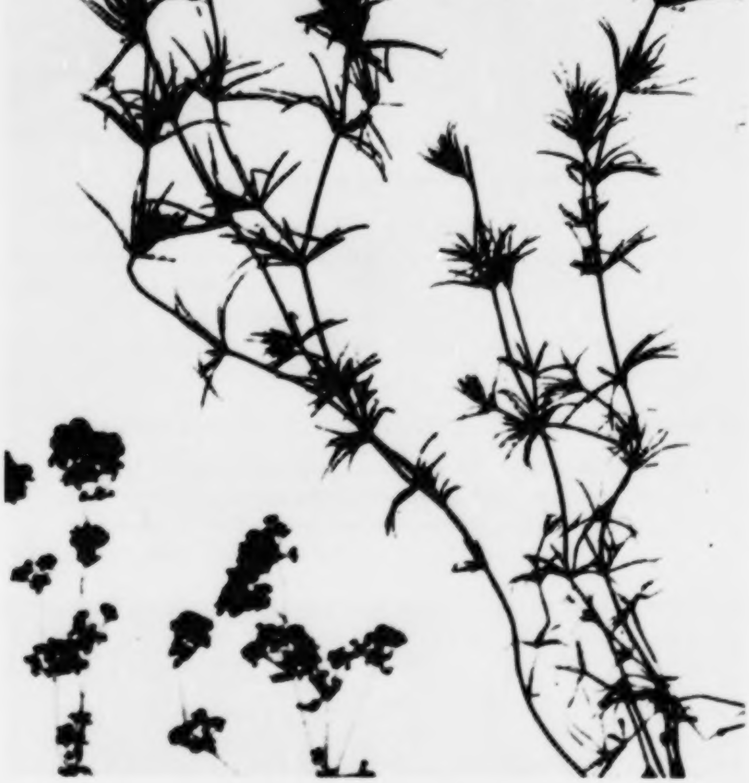

Plate 38. Muskgrass (*Chara*) (An Alga)

1. Plant body not brittle 2
2. Submersed leaves bearing small bladders, leaves irregularly forked ....Bladderwort, UTRICULARIA
2. Submersed leaves not bladder bearing 3

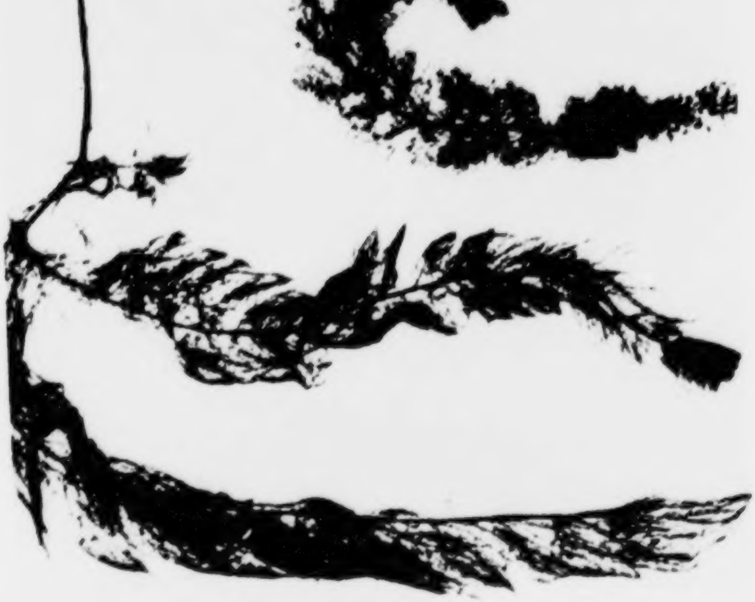

Plate 39. Bladderwort (*Utricularia*)

3. Submersed leaves compound, made up of narrow segments or leaflets 4
3. Submersed leaves simple, made up of a single narrow blade 7
4. Submersed leaves with one central axis, leaves feather-like, branches in whorls about the stem, stems usually very lax .... Water Milfoil, **MYRIOPHYLLUM**
4. Submersed leaves irregularly forking 5
5. Submersed leaves singly and alternately or irregularly borne; leaves many branched, irregularly forked and appearing as

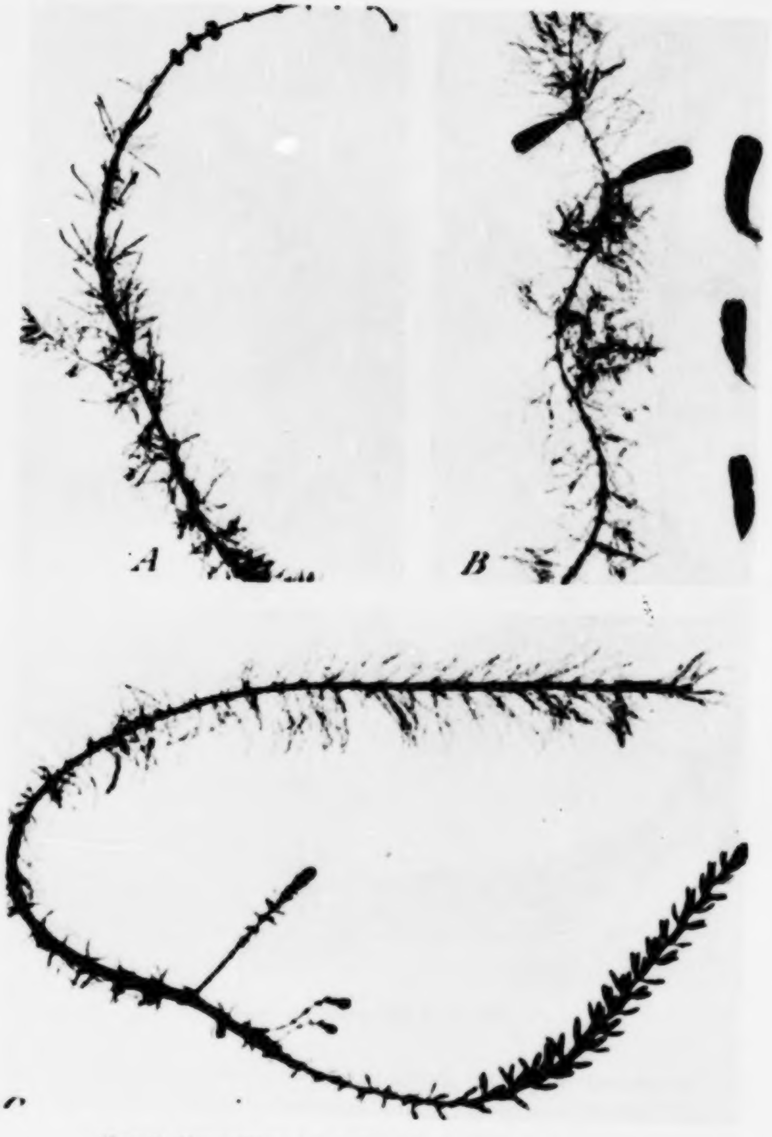

Plate 40. Water Milfoil × 1/3: A. *Myriophyllum spicatum* Linnaeus; B. *M. verticillatum* Linnaeus; C. *M. heterophyllum* Michaux.

tufts of numerous thread-like projections attached to the center stem.................. Water Buttercup, RANUNCULUS

5. Submersed leaves borne opposite each other on stem or whorled 6

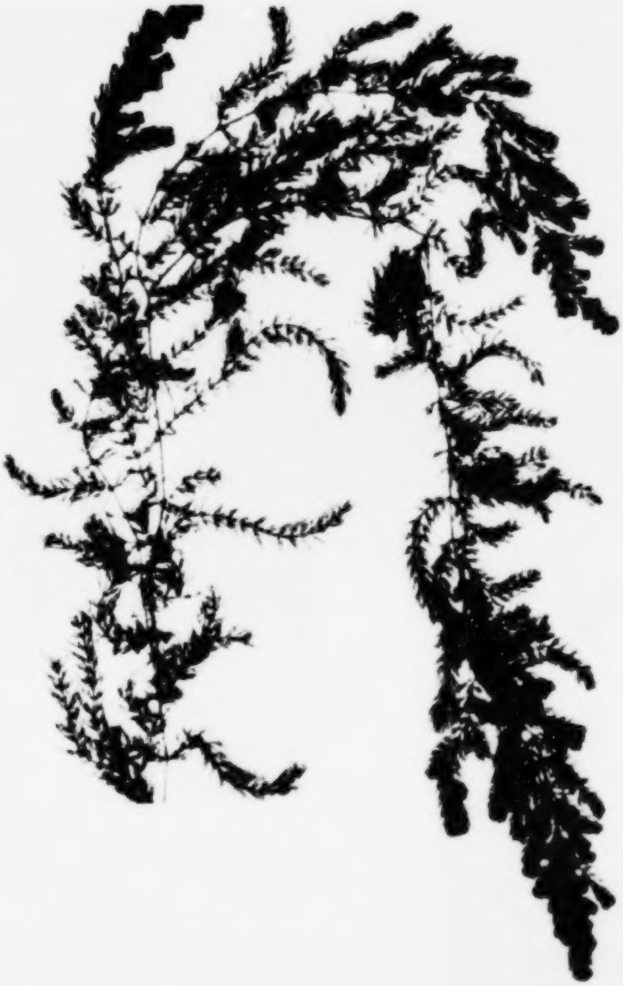

Plate 41. Coontail (*Ceratophyllum*) × ⅔.

6. Leaves stalked, fan-like, extending from opposite sides of the stem; leaflets not toothed .... Fanwort, **CABOMBA**

6. Stems with whorls of stiff, forked leaves; leaflets with toothed or serrated margins (small barbs) on one side; plant without true roots .... Coontail, **CERATOPHYLLUM**

7. Submersed leaves long and ribbon-like, at least 1/10 inch wide 8

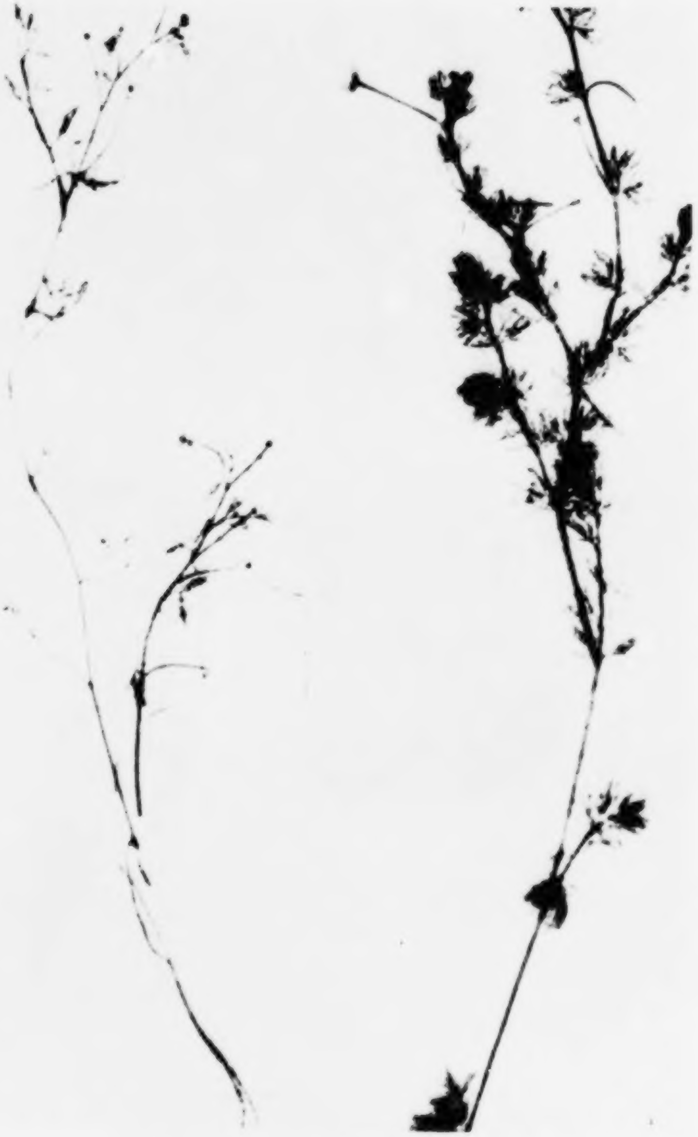

Plate 42. Water Buttercup (*Ranunculus*).

7. Submersed leaves not ribbon-like; often thread-like but if wider than 1/10 inch, less than 1 inch long....................18
8. Leaves scattered along the stem.............................. 9
8. Leaves all borne from one point..............................17

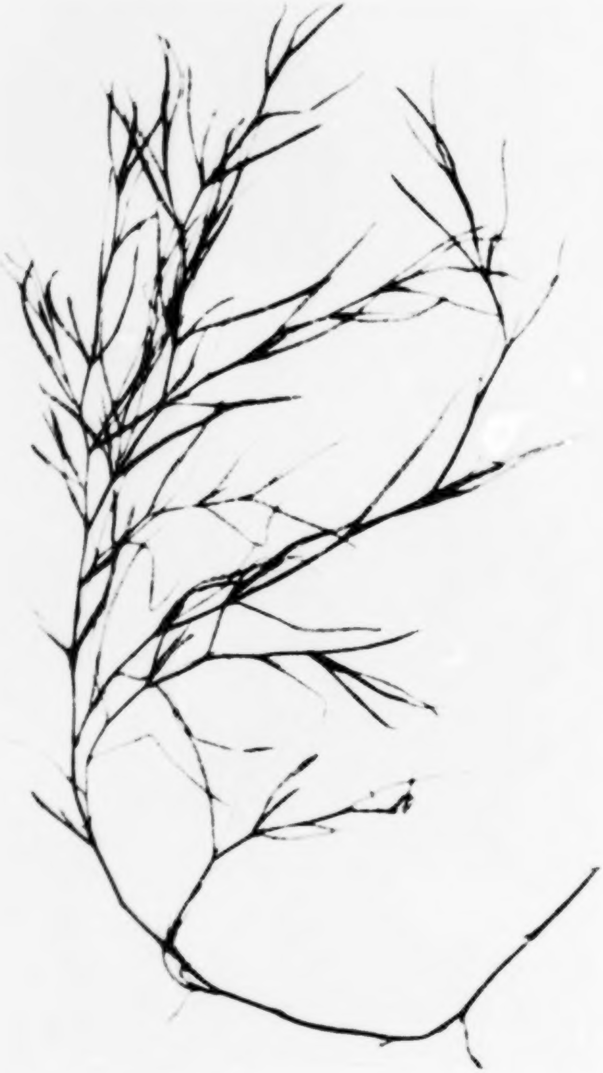

Plate 43. Water Star Grass (*Heteranthera*).

9. Leaves with mid-ribs evident when held against bright light, many species with great diversity in leaf forms Pondweed, POTAMOGETON 10
9. Leaves without mid-ribs evident when held against bright light ....Water Star Grass, HETERANTHERA

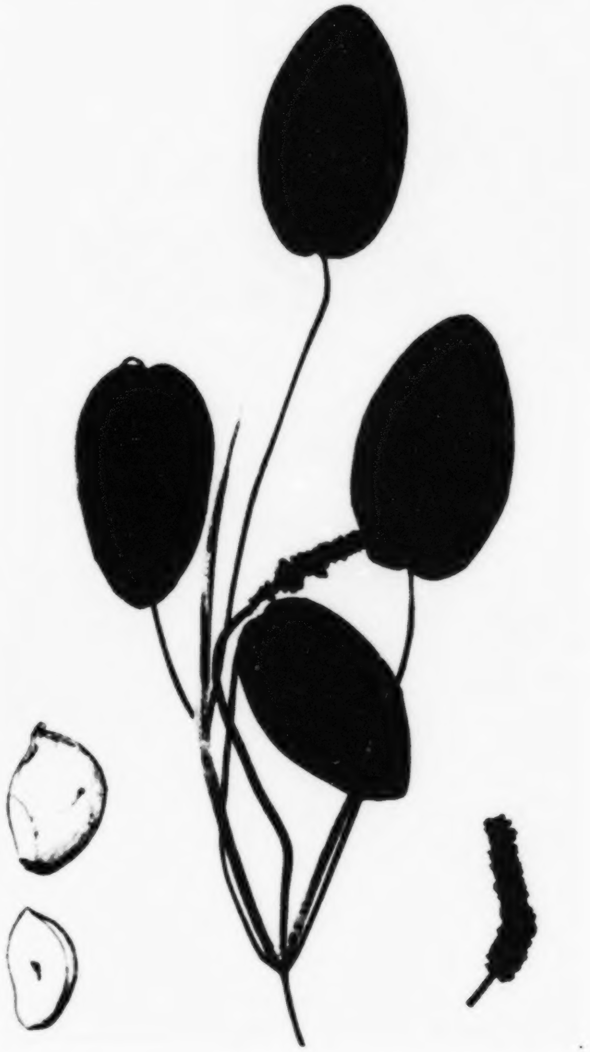

Plate 44. Floating-leafed Pondweed (*Potamogeton natans* Linnaeus).

10. Plants with both floating and submersed leaves, the floating leaves with expanded blades and differing from those submersed 11

10. Plants with all leaves alike and submersed......................14

11. Floating leaves, heart-shaped at the base, 1 to 4 inches long, waxy in appearance......................Floating-leafed Pondweed, POTAMOGETON NATANS Linnaeus

11. Floating leaves rounded at the base............................12

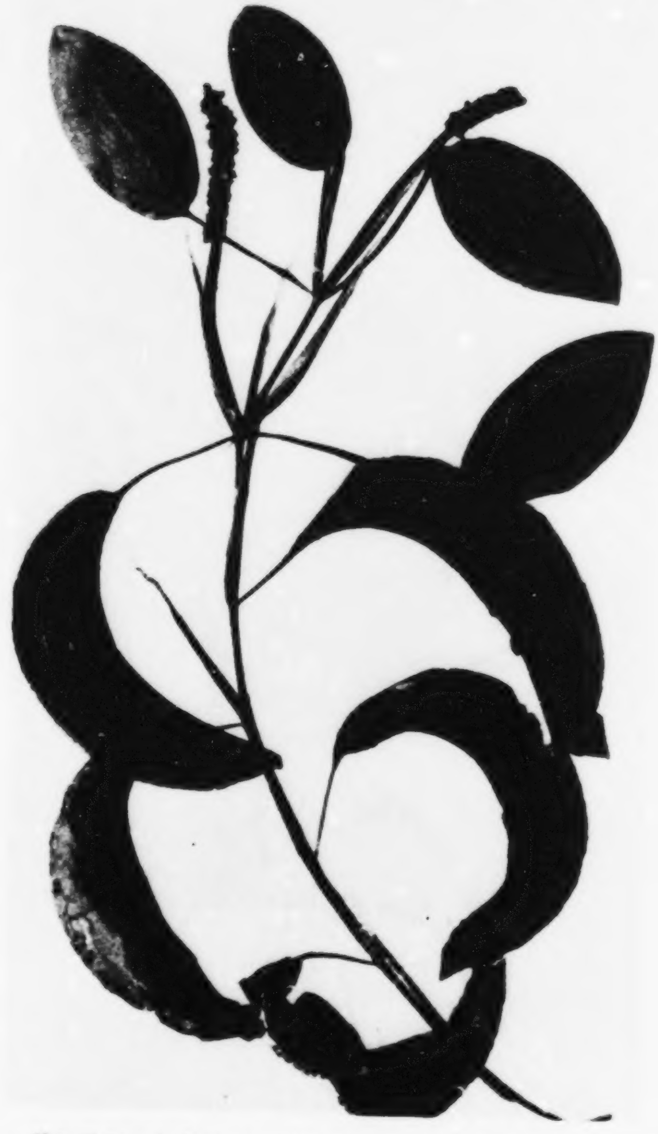

Plate 45. Large-leafed Pondweed (*Potamogeton amplifolius* Tuckerman).

12. Floating leaves with 30 to 50 nerves; submersed leaves about three times as long as broad
    Large-leafed Pondweed, POTAMOGETON AMPLIFOLIUS Tuckerman

12. Floating leaves with less than 30 nerves 13

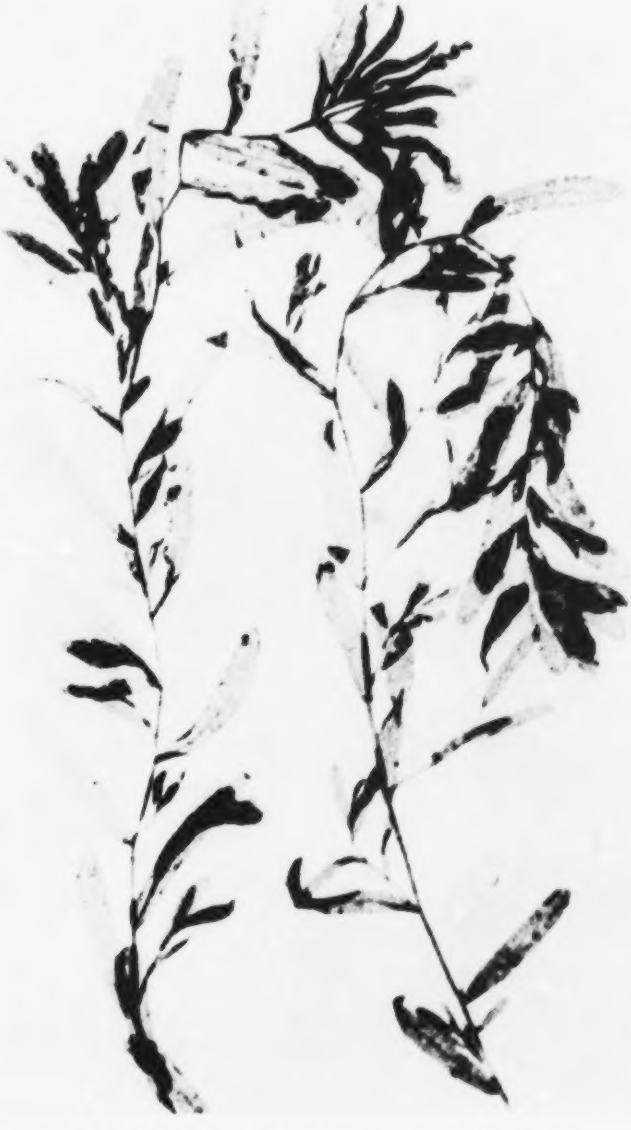

Plate 46. Curly-leafed Pondweed (*Potamogeton crispus* Linnaeus).

13. Upper submersed leaves with long stalks ....Pondweed,
POTAMOGETON NODOSUS Poiret

13. Submersed leaves not as above but with an abrupt awl-shaped tip ....Pondweed,
POTAMOGETON ANGUSTIFOLIUS Berchtold

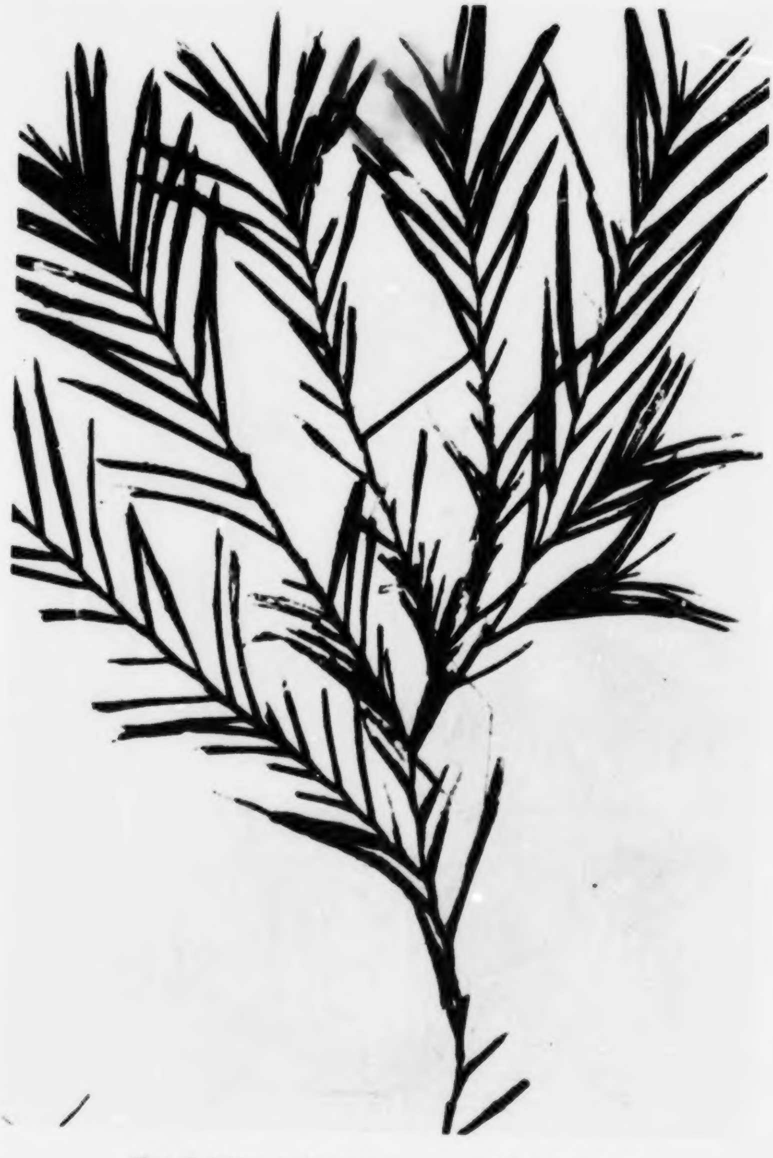

Plate 47. Robbins Pondweed (*Potamogeton robbinsii* Ockes).

14. Margins of the thin leaves crimped and toothed, the marginal serrations visible to the naked eye
Curly-leafed Pondweed, POTAMOGETON CRISPUS Linnaeus
14. Margins of leaves not visibly toothed........................15

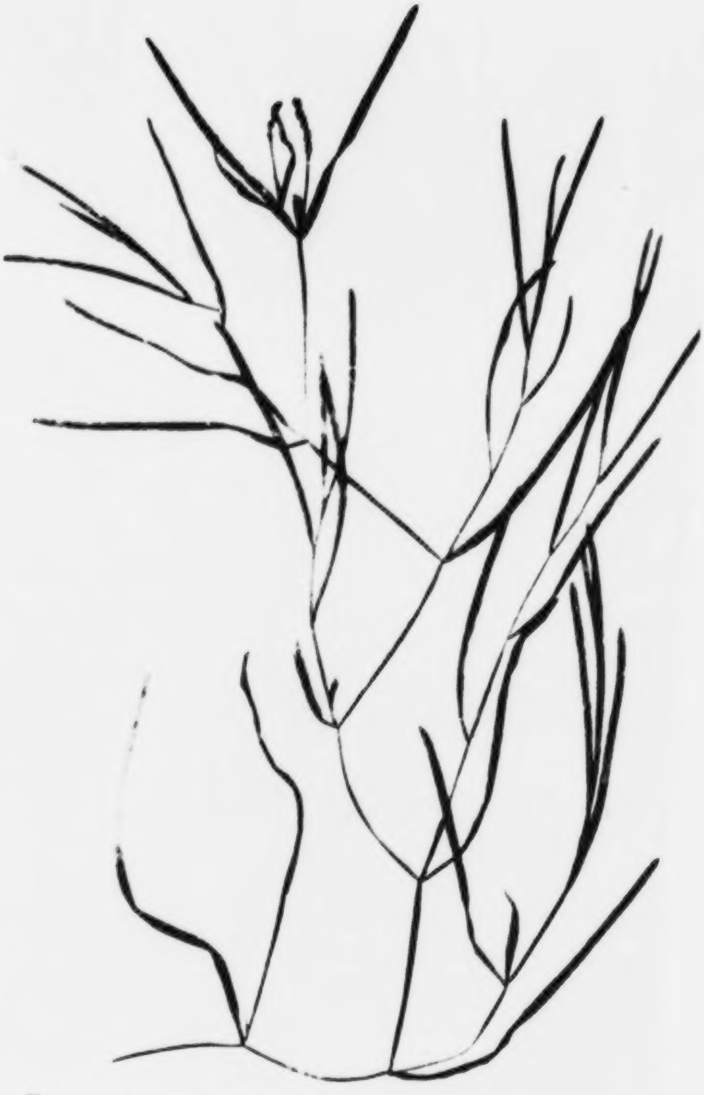

Plate 48. Flat-stemmed Pondweed (*Potamogeton zosteriformis* Fernald)

15. Leaves minutely toothed on the margins, visible when magnified; leaves extending stiffly in opposite directions so that whole plant appears flat; only midvein prominent
Robbins Pondweed, POTAMOGETON ROBBINSII Oakes

15. Not as above..16

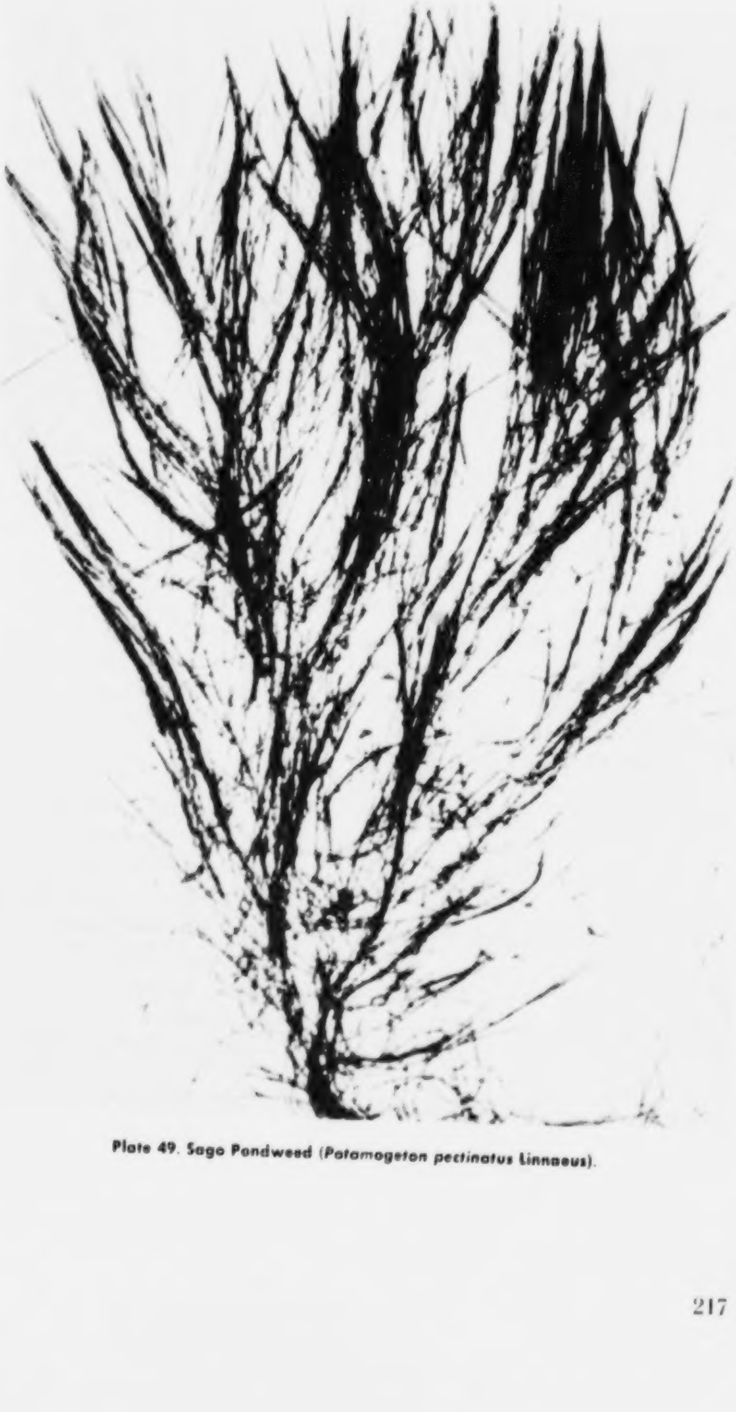

Plate 49. Sago Pondweed (*Potamogeton pectinatus* Linnaeus).

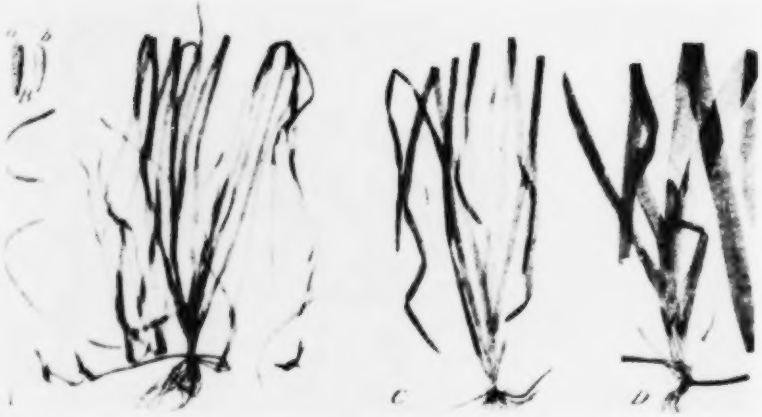

Plate 50. Wild Celery (*Vallisneria*) × 1/4: A. Specimen with fruit and tubers; C. Northern form; D. Southern form.

16. Stems much flattened and winged, about as wide as the leaves; leaves 1/12 to 1/5 inch wide . . . . . Flat-stemmed **Pondweed,**
POTAMOGETON ZOSTERIFORMIS Fernald

16. Leaves threadlike, long, rounded, and slender, rarely exceeding 1/10 inch wide, oriented into a lax, diffuse, branched spray. The "bunched" appearance of the threadlike rounded leaves as they float in the water readily distinguish sago pondweed from others of group . . . . Sago **Pondweed,**
POTAMOGETON PECTINATUS Linnaeus

17. Leaves very long and ribbonlike; when examined with hand lens, showing a central dense zone and a peripheral less dense zone; flowers borne on a long stem that forms a spiral after fertilization . . . . Wild Celery, **VALLISNERIA**

17. Leaf, when examined with hand lens not showing zones as above . . . . Water Plantains, **ALISMATACEAE**

18. Leaves opposite, all leaves elongated and narrow, many times longer than broad, and enlarged or dilated at base. Bunches of smaller leaves near the leaf base . . . . Bushy **Pondweed,**
NAJAS

18. Leaves whorled, usually 3 in each whorl. (sometimes 4)
Waterweed, **ANACHARIS** (Elodea)

PLANTS ERECT AND EMERGENT

1. Leaves more than 10 times as long as broad 2
1. Leaves less than 10 times as long as broad 9

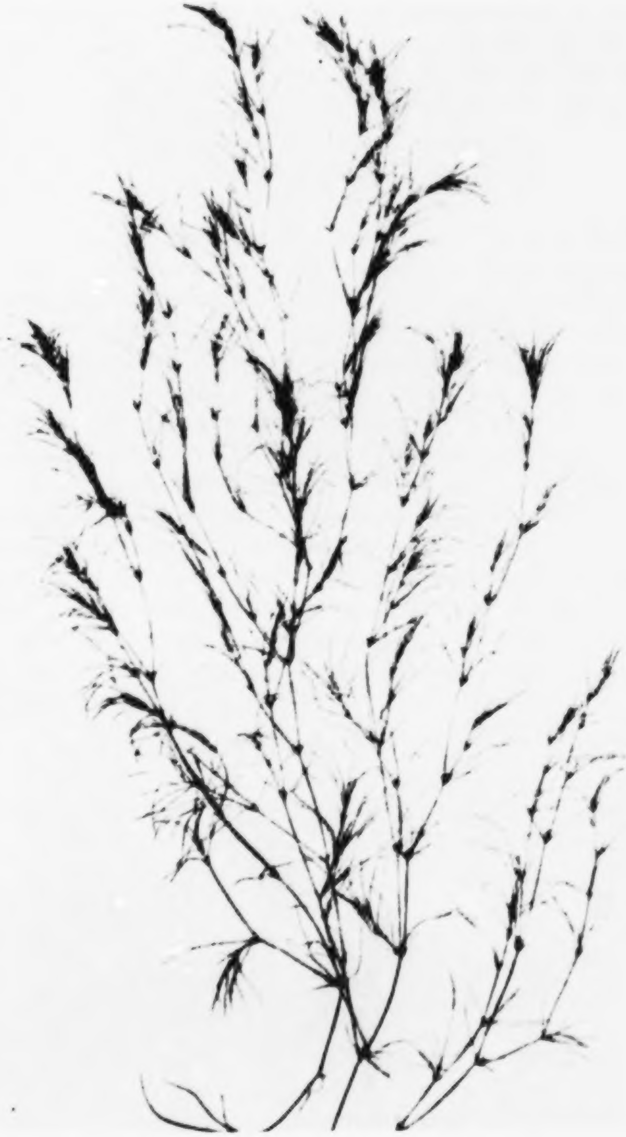

Plate 51. Bushy Pondweed (*Najas*) × ⅝.

2. Base of stem triangular in cross section, the three angles in some cases so rounded as to make the stem appear almost round 3

2. Base of stem not triangular 5

3. Three cornered seeds, usually straw colored, enclosed within a loose elongated sac; a low-growing grasslike plant ...... Sedge, CAREX

3. Seeds not enclosed in a loose elongated sac 4

4. A single flower or seed-bearing structure on the tip of the stem .... Spike Rush, ELEOCHARIS

4. Stem with one or more leaves extending beyond the spike or seed-bearing structure .... Bulrush, SCIRPUS
(The hardstem bulrush has long, hard, slender, dark olive-green stems, $\frac{1}{8}$ to $\frac{3}{8}$ inch at the base, extending 3 to 5 feet above the water surface; the softstem bulrush has soft stems of light green color, $\frac{3}{10}$ to 1 inch thick at the base.)

5. Leaf with a collarlike appendage, membranous or composed of hairs at the junction of the leaf blade and that part of the leaf that is wrapped around the stem 6

5. Leaf without collarlike appendage mentioned above 8

6. Seed or flower-bearing structure composed of scales with fringed margins and overlapping in a single row ...... Cut Grass, LEERSIA

6. Flower-bearing structure not as above 7

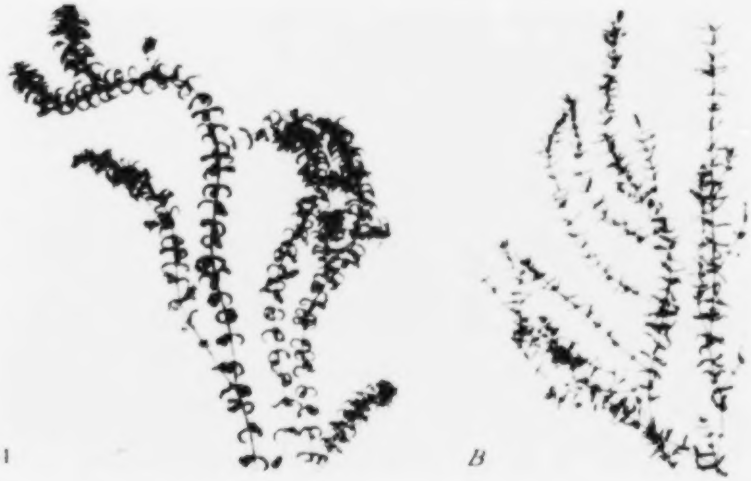

Plate 52. Waterweed × $\frac{3}{5}$: A. *Anacharis canadensis* Michaux, B. *A. occidentalis* Pursh.

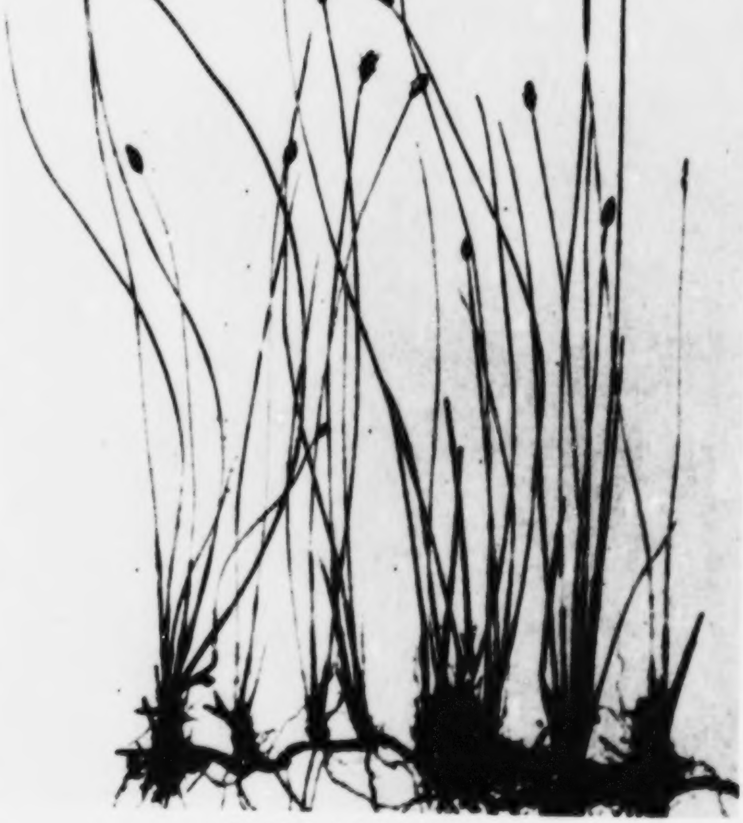

Plate 53. Spike Rush (*Eleocharis*).

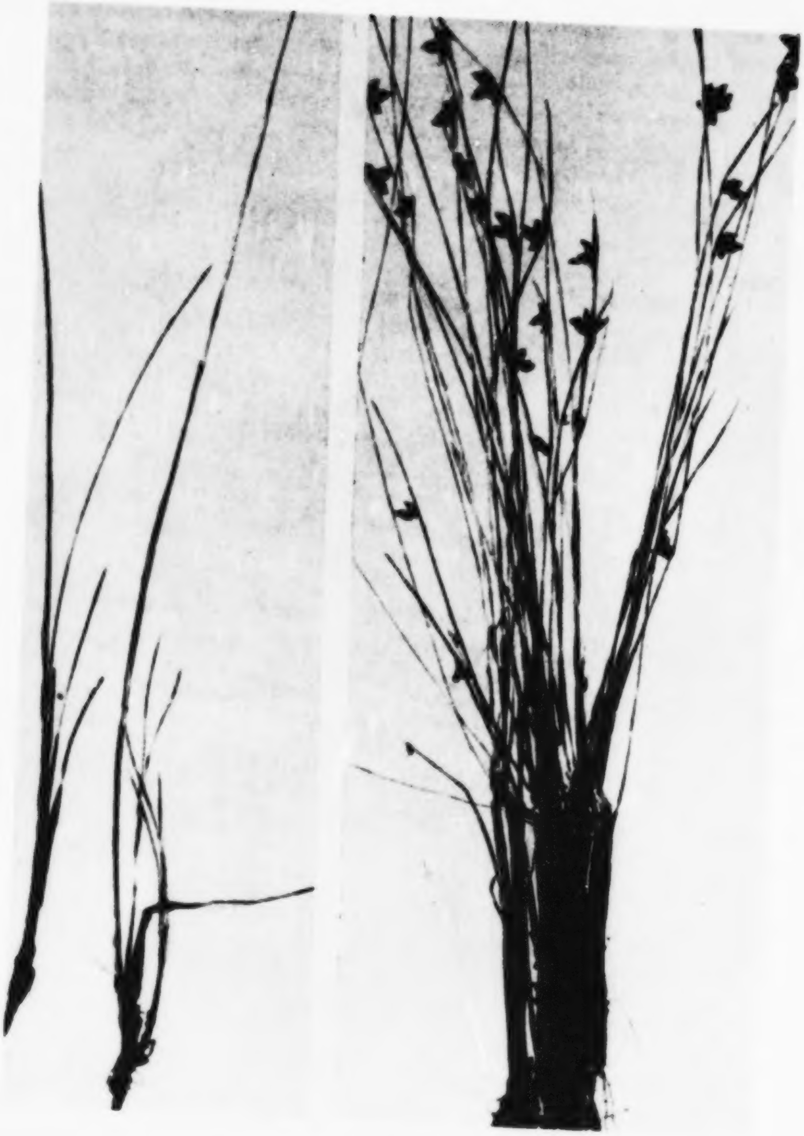

Plate 54. Bulrush (*Scirpus*)

7. Flowering heads composed of small seeds with long silky hairs, appearing as a silky mass. The rootstocks are stout, making it a difficult plant to pull up. Plants are 6 to 12 feet tall..................................Reed Grass, PHRAGMITES

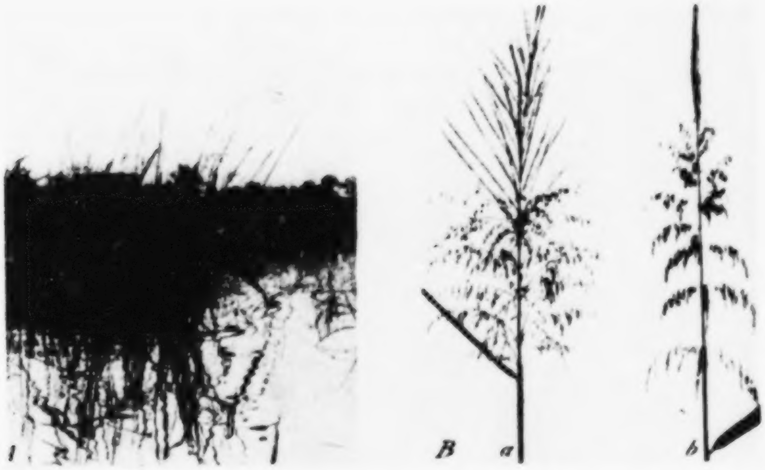

Plate 55. Wild Rice (*Zizania*): A. Stand of Broad-leaved form; a. broad-leaved; b. narrow-leaved form.

7. Flowering part of plant much branched, but not as closely packed as in **PHRAGMITES**. Seeds much larger, about ¾ inch long. Plants with short roots and easily pulled up .... Wild Rice, **ZIZANIA**

8. Flowers borne in closely packed cylindrical spikes, seeds very small .... Cattail, **TYPHA**
(The common cattail has flat leaves about 1 inch wide; the narrow-leaved cattail has leaves somewhat rounded on the back that are ⅛ to ⅞ inch wide.)

8. Flowers in spherical heads, seeds larger, up to size of corn kernel; leaves shallowly and broadly triangular in cross-section .... Burreed, **SPARGANIUM**

9. Leaves arising at intervals along the stem 10

9. Leaves arising at base of the plant 11

10. Plants with jointed stems, swollen at the joints, or with creeping rootstocks; stems with alternate, simple leaves .... Smartweed, **POLYGONUM**

10. Stems prostrate or creeping, branched, and often jointed and rooted at the joints; leaves opposite; spreading plant, often forming floating mats over extensive water areas crowding out other plants; broken-off branch fragments root readily, and stems may elongate as much as 200 inches in one season .... Alligatorweed, **ALTERNANTHERA**

11. Fleshy or tuber-bearing rootstocks and rosettes of sheathing basal leaves; leaves variable, some kinds arrowhead shaped .... Duck Potato, **SAGITTARIA**

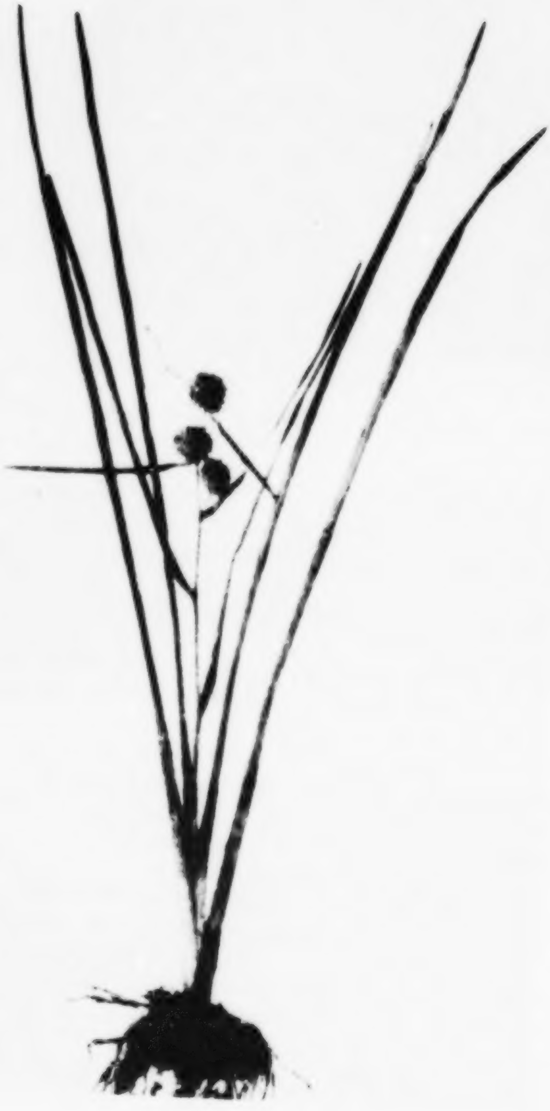

Plate 56. Burreed (Sparganium).

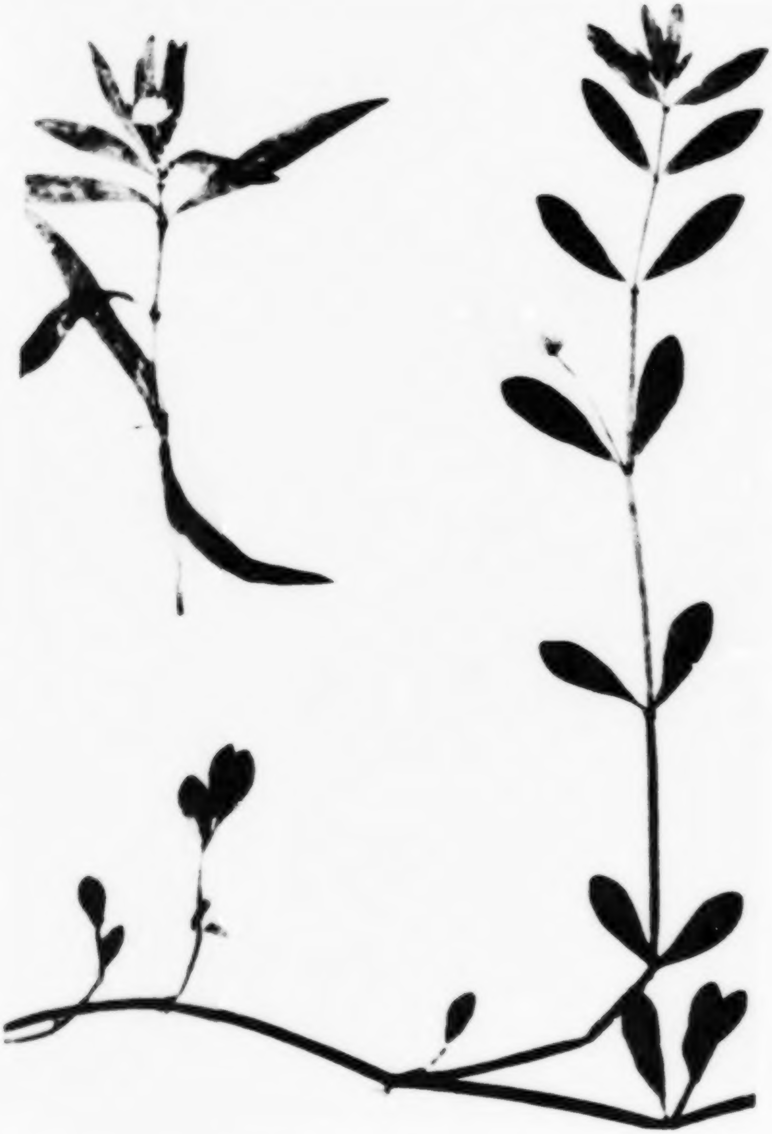

Plate 57 Alligatorweed (*Alternanthera*).

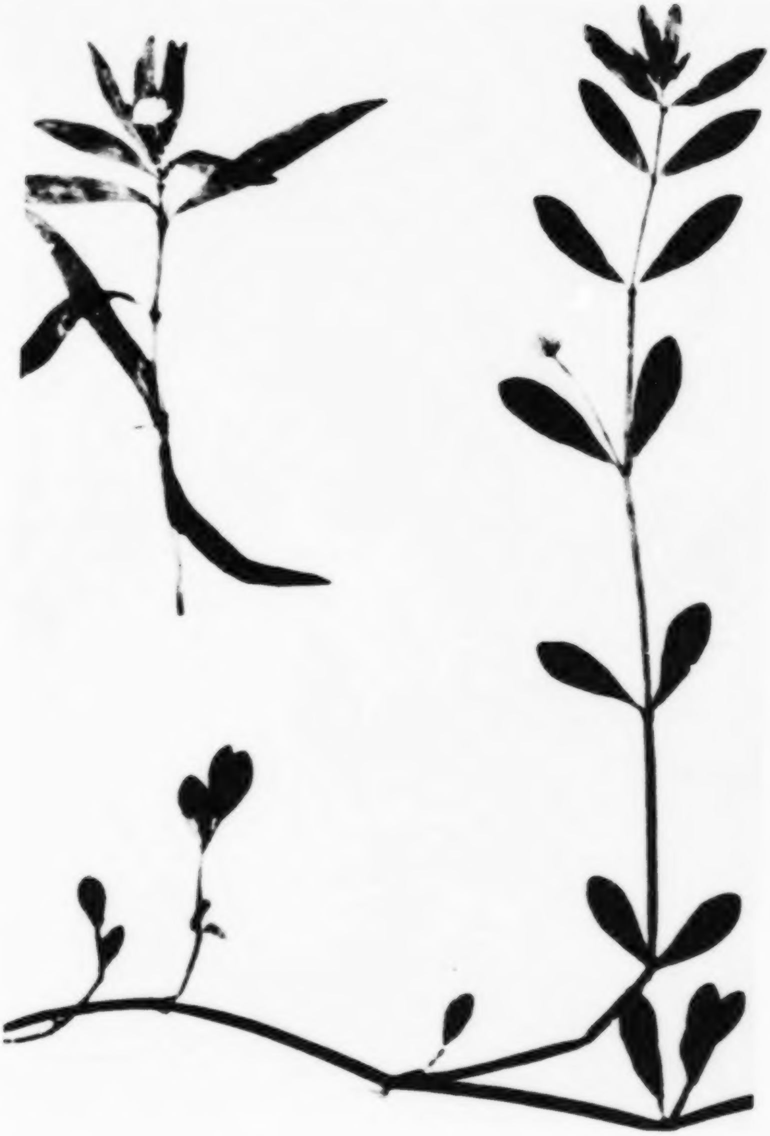

Plate 57 Alligatorweed (*Alternanthera*).

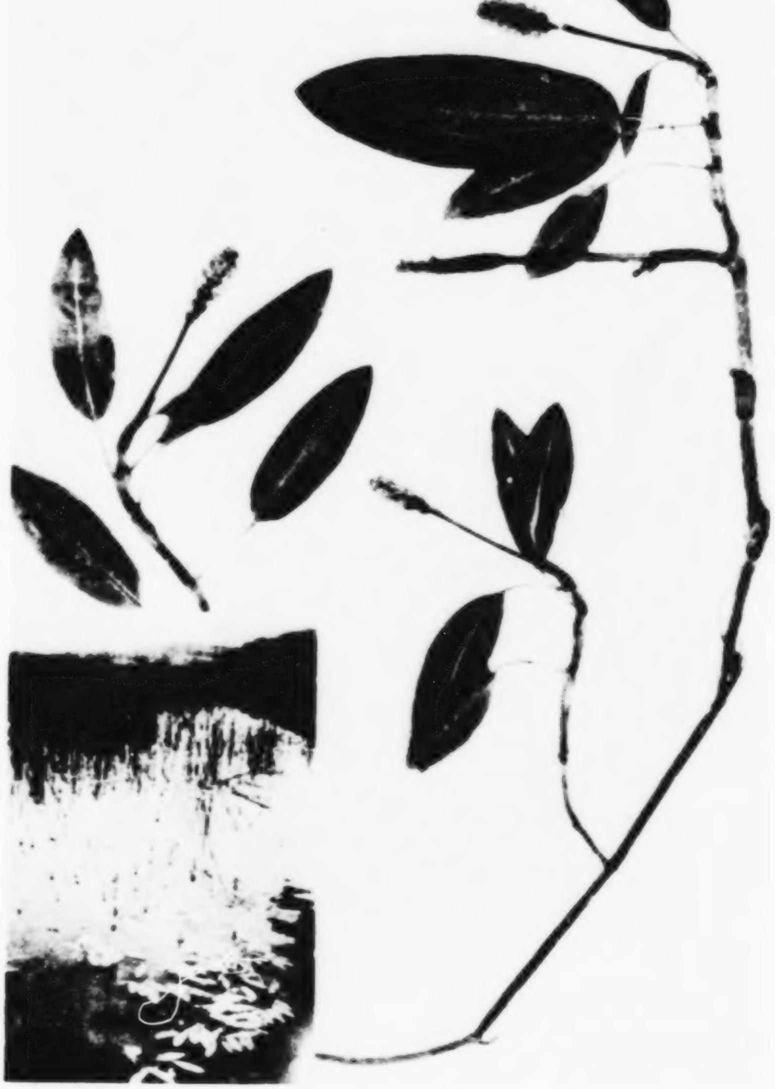

Plate 58. Smartweed (*Polygonum*) × 2/9

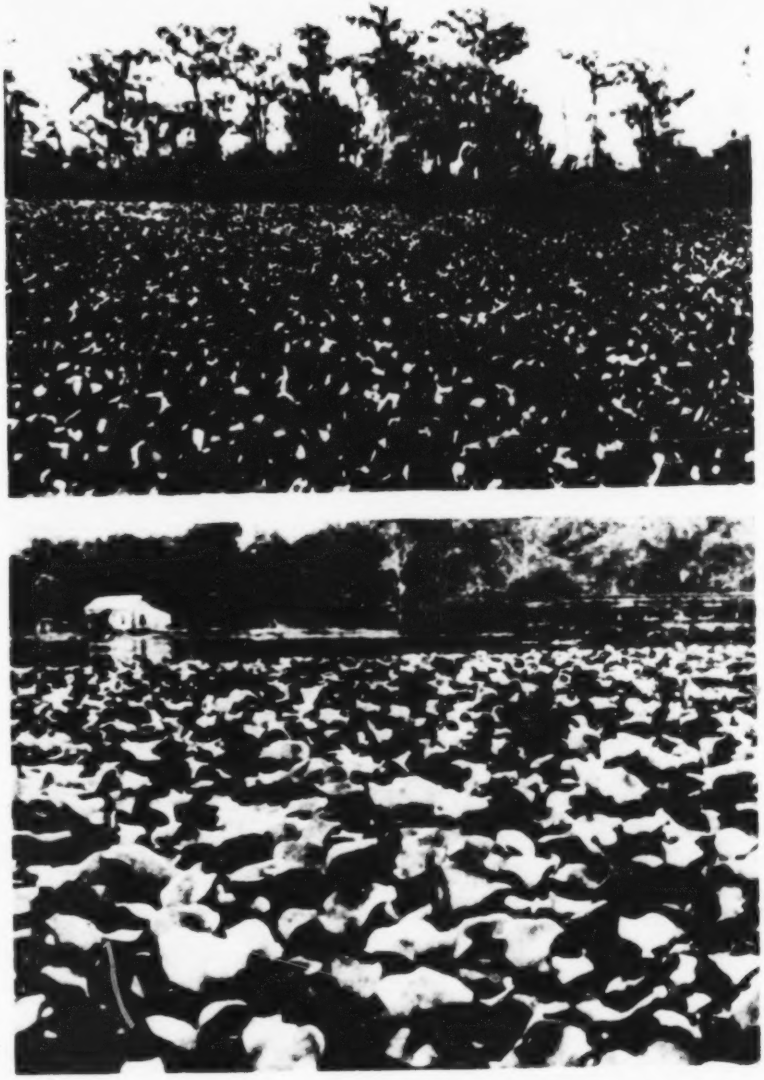

Plate 59. Waterhyacinth (*Eichhornia*).

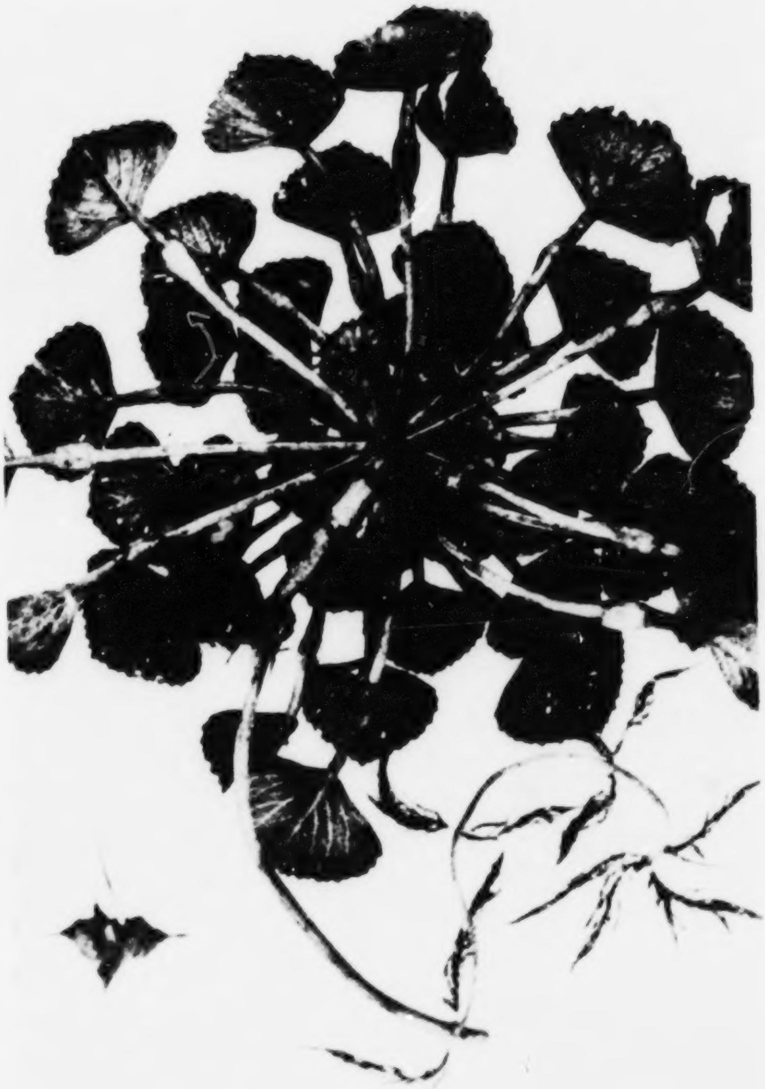

Plate 60. Waterchestnut (*Trapa*) × ¼.

11. Not as above, floating plants 12

12. **Plants** floating with fibrous, branched roots and rosettes of stalked leaves, the leaf stalks often inflated and bladder-like . . . . Waterhyacinth, **EICHHORNIA**

12. **Plants** with floating rosettes of stalked leaves, commonly several rosettes produced on branches of the same plant at the end of flexible, cordlike, sparsely-branched submersed stems; plant thrives at depths of 2 to 5 feet and favors muddy bottoms with high organic content; leaf stalks inflated, but not as conspicuously as in waterhyacinth
Waterchestnut, **TRAPA**

20

Control of Excess Production

General Control

ULTIMATE control of nuisance aquatic organisms can be accomed only by taking appropriate actions against the basic cause. Generally the introduction of organic materials or certain inorganic nutrients into the Nation's waterways is responsible for the explosion of a plant or animal population into a nuisance state. Drainage from fertilized lands, inadequately treated domestic or industrial waste discharges, street and storm drainage, improperly managed refuse dumps, wastes from confined animal feeding areas and other agricultural activities, irrigation return flows, improper logging practices, construction site siltation, and inadequate treatment of rural sanitary wastes each contributes its abundant share to the receiving water degradation. Each waste source, point and non-point, must be treated or controlled adequately if this Nation's waters are to be used to the extent that is and will be necessary to respond to the needs of this and the future society.

A maintenance concept must be adopted and implemented by all users of streams, lakes, ponds, or reservoirs. The water front is an aquatic extension of the surrounding lands. To achieve the most lasting beauty, it must be maintained periodically in a fashion similar to that of private lawns or the areas adjacent to the Nation's parkways. If not, nuisances and unsightliness will prevail. Controls developed to cure water ills other than those that will correct the basic cause are not singular operations. They are remedial, temporary measures only. They provide some degree of transitory success, and they must be repeated at intervals throughout the season to maintain the degree of water quality ncessary for specified uses. The mechanism triggering a nuisance development is usually such that it will re-establish itself another year, thus continuous surveillance and maintenance are necessary components of water management.

Controls designed to correct the basic cause often involve the construction and continuous operation of a treatment system that will remove those substances from the waste water that are contributing to the receiving waterways' degradation. Such waste water treatment systems often involve the expenditure of substantial sums of money, as well as a great deal of planning and community or corporate effort. Furthermore, it must be recognized by the citizens affected by the degraded water that the planning and construction of waste water treatment plants involve a considerable period of time between the date of initiation and the date of operation. An additional factor of consideration is that waterways that have been polluted will require time to rid themselves of the pollution and regain a quality and flora and fauna that will support a higher degree of future water use.

Slimes

Much work has been done on the control of *Sphaerotilus* because of the severity of the problems that it causes in activated sludge sewage treatment plants, cooling towers, and receiving waterways. The use of chlorine has been considered to be the most feasible substance for large scale use to control a slime organism such as *Sphaerotilus*. The discharge of residual chlorine in the waste water to a receiving waterway has created additional problems because of its toxicity to fish and other aquatic life.

In water treatment plants a high initial dose of chlorine followed by the maintenance of residual chlorine in the effluent water has been found necessary to remove established slime growths. On a routine basis, of course, the addition of chlorine to water prior to use imposes an added cost-burden upon the consumer that would be unnecessary with appropriate waste water treatment or control upstream.

Sphaerotilus slime growths have been controlled through the practice of an intermittent discharge of waste waters. To effect such controls, it appears from the literature that waste holding capacity must provide for five or six days of waste retention with a discharge of the waste materials over a one- or two-day period.

Chlorination of water appears to be the most satisfactory method of controlling the development of other iron bacteria. Free chlorine residual must be maintained throughout the distribution system. When iron bacteria have been present, and although the kill may be effective, tastes and odors in the water supply are still possible from decomposing organisms.

When iron bacteria grow profusely in drainage ditches, and an infestation of a lake or reservoir may be likely as a result, effective control has been accomplished with the application of copper sulfate at a dosage rate of about three parts per million of the blue vitriol. As with the use of chlorine, great care must be exercised in the use of copper sulfate for the control of aquatic nuisances to prevent damage to organisms desired by man.

There appears to be no straightforward solution to the technological problem of controlling massive pollution by sulfate-reducing bacteria. Sterilization of the water is almost always out of the question. There are some expedient measures available that provide air or oxygen to the water as a means of inhibiting the organism's growth. If the water is aerobic, the growth of these organisms can be alleviated. Acidification to a pH value below 5 will prevent the growth of sulfate-reducing bacteria. Most clean water associated aquatic life will also be inhibited in waters with this pH characteristic.

The chromate ion is an inhibitor of ordinary corrosion, as well as a powerful inhibitor of the growth of sulfate-reducing bacteria. It has been used at concentrations as low as 2 mg/l to stop development of these nuisance organisms in confined areas. The application of sodium nitrate has been found helpful in reducing the evolution of hydrogen sulfide. Sodium nitrate provides oxygen to the water, as well as nutrient for the photosynthesizing plants.

It becomes readily obvious that the temporary control of these, or for that matter other aquatic organisms, is an expensive and continuing operation. The most lasting results will be obtained by addressing remedial actions to the cause of the problem.

Plant Nuisances

Methods have been developed and perfected that effect an adequate temporary reduction and control of plant nuisances under a number of circumstances. Controls may be either mechanical or chemical and their selection and use depend upon the the nature and scope of the problem, the type and the extent of the control desired, and comparative costs of alternative control measures. Mechanical controls are limited principally to rooted aquatic plants with the exception that microstrainers have been employed successfully in the removal of algae from water supply intakes and other areas. Chemical controls have been used for algae and vascular aquatic plants. Each control has its limitations based upon the dimensions of the area to be treated and the relative costs of the control operation.

From the standpoint of nutrient removal and as an asset to eutrophication control, harvesting the aquatic crop annually or at more frequent intervals would be advantageous. The economics of present harvesting technology and the scope of the problem however necessitate a critical evaluation of the benefits derived as opposed to the cost involved. As stated in an earlier chapter, the volume and weight of aquatic vegetation presents certain constraints upon feasible harvesting procedures. Aquatic vegetation is about 90 percent water by weight and this fact adds a tremendous burden to the collection and transportation of the harvested vegetation, as well as the use to which it may be put.

Some methods and equipment used for the physical and mechanical removal of water weeds are reservoir draw down and drying, burning, hand pulling, hand cutting, hand raking, chain dragging, hand operated under-water weed saws, and power driven under-water weed cutting and weed removal units. The type of control employed depends on the field situation, the extent of control required, and the labor and other costs involved. Mechanical control has the advantage of removing the vegetation and its contained nutrients from the waterway, as well as precluding the effects of decomposition products. Such controls are especially valuable to reclaim shallow areas with vegetative nuisances. Mechanical controls, on the other hand, substantially exceed costs of chemical controls in most instances in both monetary and personnel resources required to accomplish the task.

Specific chemical control measures depend upon the type of nuisance and local conditions. A good algicide or herbicide must: (1) be reasonably safe to use; (2) kill the specific nuisance plant or plants; (3) be non-toxic at the plant killing concentration to fish, fish food organisms, and terrestrial animals that use the water; (4) not prove seriously harmful to the ecology of the general aquatic area; (5) be safe for water contact by humans or animals or provide suitable safeguards

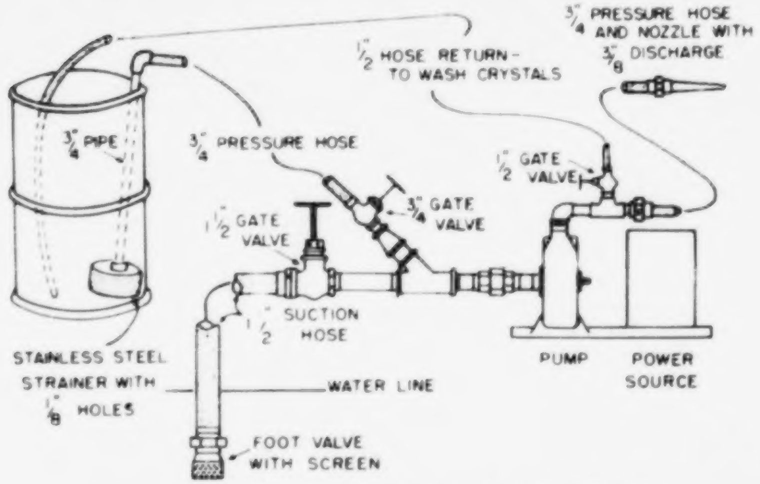
3/4" PRESSURE HOSE AND NOZZLE WITH 3/8" DISCHARGE
1/2" HOSE RETURN - TO WASH CRYSTALS
3/4" PIPE
3/4" PRESSURE HOSE
1/2" GATE VALVE
3/4" GATE VALVE
1 1/2" GATE VALVE
1 1/2" SUCTION HOSE
STAINLESS STEEL STRAINER WITH 1/8" HOLES
WATER LINE
FOOT VALVE WITH SCREEN
PUMP
POWER SOURCE

Figure 19. Equipment designed for algal control. Blue vitriol crystals are placed over perforated drum in chemical solution tank.

during the unsafe period; and (6) be of reasonable cost. The cost figure assumes added significance, and depends upon the physical dimensions of the waterway on which control is desired. A procedure that might be suitable for a pond from both the cost and toxicity standpoint might not be feasible in a control program for specific areas on a large lake or impoundment.

For the chemical control of algae, it may be necessary only to know the acreage of water requiring treatment and the methyl orange alkalinity of the water to be treated. For the chemical control of vascular aquatic plants it is necessary usually to know the volume of water receiving treatment. A formula is used to ascertain the amount of chemical to apply to a given area: Length (ft.) times width (ft.) times average depth (ft.) times 62.4 (wgt. of a cu. ft. of water) divided by 1,000,000 equals the pounds of chemical (active ingredient) needed to give a concentration of 1 mg/l. This number multiplied by the required chemical concentration in milligrams per liter for treatment equals the pounds of chemical needed for the designated area. Various formulations of chemicals are used. For example, a formulation containing two pounds of active ingredient per gallon would necessitate dividing the pounds of chemical by two to arrive at the gallons of commercial formulation required to control the specific nuisance.

Algal Control

Since 1900, copper sulfate (blue vitriol) has been used for the control of algae. The solubility of copper in water is influenced by the pH and alkalinity, as well as temperature. Thus, the dosage required for algal control depends upon the chemistry of the water being treated, as well as the susceptibility of the particular organisms to the copper. Arbitrary dosage rates have been used successfully. These generally prescribe a concentration of 0.3 mg/l commercial copper sulfate ($CuSO_4 \cdot 5H_2O$) for the total volume of water when the total methyl orange alkalinity is below 40 mg/l. This dosage is comparable to 0.9 pounds of copper sulfate per acre foot of water. In waters where the total methyl orange alkalinity exceeds 40 mg/l the dosage rate is increased to 1 mg/l for the upper two feet of water regardless of actual depth, or an equivalent of 5.4 pounds of the commercial copper sulfate per surface area to be treated.

Algal control treatments can be complete or marginal depending upon the size, shape, relative water fertility and estimated cost of the project. Complete treatment is the systematic application of a calculated amount of chemical over the entire surface area affected by the nuisance. It ensures that a major proportion of the total algal population is eliminated at one time so that a longer recovery period is required before an algal bloom reappears. The interval between neces-

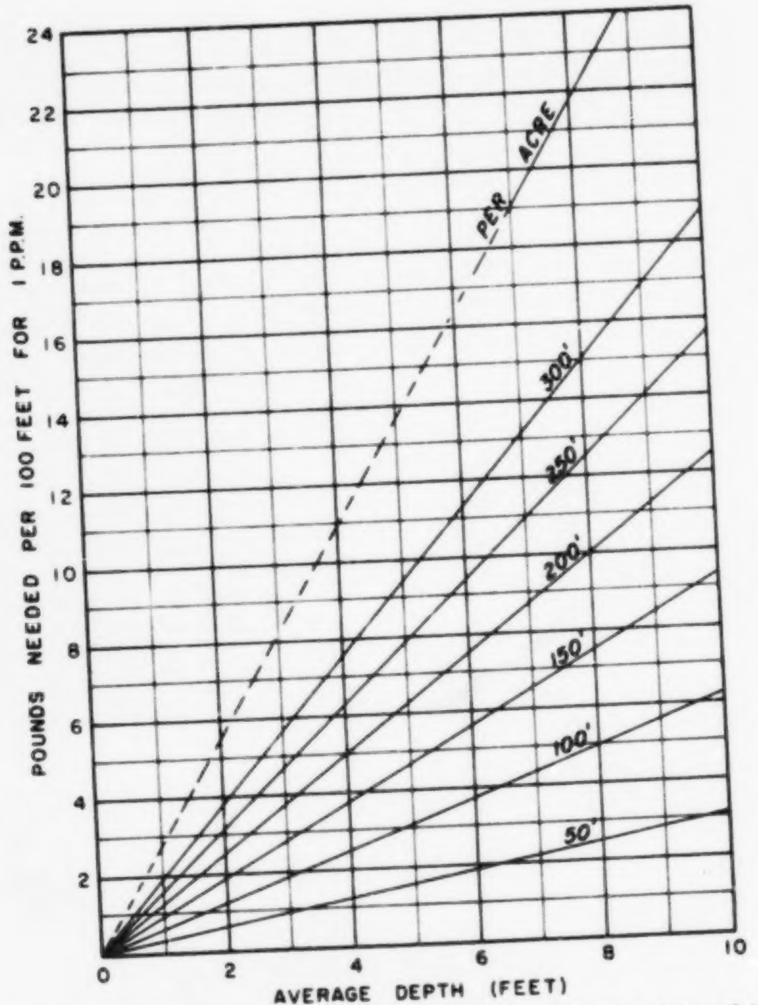

Figure 20. Chemical Dosage Chart. To achieve a chemical concentration of 1 mg/l in water having an average depth of 8 feet requires 10 pounds of the active chemical for an area 200 feet by 100 feet, or 21.8 pounds per acre.

sary complete treatment will be correlated directly with climatological conditions and the avaiable nutrients used by the remaining algal cells that are not killed as a result of the chemical application. One to three complete treatments per season should be sufficient to give reasonable control within the lake environment.

Marginal treatment, on the other hand, is designed to obtain temporary relief in a restricted area where more extensive activity is not feasible or is financially impossible. In this procedure a strip of water 200 to 400 feet wide lying parallel with the shore and all protected bays are sprayed in the same manner as in a complete treatment operation. No other part of the total area is treated even though many algae may be present. As a result of marginal treatment the algal population and the odor intensity along the lake's periphery are reduced. The duration of freedom from the algal nuisance following marginal treatment is dependent upon the density of the algal population in the center of the lake and its ability to infiltrate the treated area through the actions of winds, waves, and currents. Marginal treatment must be repeated oftener than that of complete treatment.

Copper sulfate may be applied to a given waterway by bag dragging, dry feeding, liquid spray, or an airplane application of either dry or wet materials. Because rapid and uniform distribution of the algicide is essential, the size and scope of the problem determine to some extent the method employed.

For maximal effectiveness, algal control measures should be undertaken before the maximal development of the algal bloom. If the problem area cannot be treated before the algal population has become dense, judgment must be used in determining the area that should receive treatment at a given time. When organic materials such as algae or aquatic weeds are killed instantly, their decomposition may result in sufficient oxygen use to remove from the water the oxygen required for the support of fish and other aquatic life. A fish or organism kill will result from this situation. When the algal scum is dense,

Plate 61 Mechanical weed cutting and removal

it is good practice to subdivide the total area to be treated into sections and control the nuisance with chemicals in one section at a time. Other sections may be treated after an interval of seven to ten days to ensure that sufficient dissolved oxygen is present to satisfy the oxygen demands of the decomposing algae.

Any chemical applied to water for the control of the problem must be used with caution and the benefits to be derived, as well as the environmental costs of such an operation, must be evaluated. Obviously the chemical employed is toxic to aquatic life because the purpose of the application is to kill and thereby control a portion of the biotic system. The effects of the chemical on that aquatic life necessary for man's water uses, and the extent to which these beneficial organisms will be injured either directly or subtly by the chemical application, must be understood and considered before a decision is reached to apply the chemical. The necessity and probability of additional applications and the cumulative effects of such additions on the aquatic ecosystem must receive similar consideration.

Vascular Plants

In the control of submersed aquatic plants it is often desirable to concentrate control efforts on localized areas along the shoreline such as bathing beaches and around piers and to develop channels through weed beds so that boaters will have access to deeper water. Sometimes it is advantageous to treat more extensive areas in an effort to curtail an advancing population of a weed species such as Eurasian watermilfoil (*Myriophyllum spicatum* Linnaeus). Chemical controls of aquatic vegetation, both algae and vascular plants, must be regarded currently as a temporary remedy for the situation. The control of vascular plants should last for the season during which the control is applied. When nutrients and other factors are suitable, the removal of a vascular plant population may promote the growth of phytoplankton or a bottom dwelling alga such as *Chara*. The successive growth of these organisms is stimulated by a release of nutrients to the water from the decomposing vascular plants that have been killed by the chemical and the penetration of sunlight through the water mass. Conversely, the control of an algal population often gives rise to the development of rooted aquatic plants within the ecosystem. Thus, the control of one nuisance may well stimulate the occurrence of another under suitable conditions and necessitate additional control actions.

The control of nuisance aquatic vegetation by biological or viral means is in the research and demonstration phase. Some work has been done with plant-eating fish, as well as certain plant-eating insects, but an ultimate solution to the vast aquatic nuisance problem that faces many sectors of this Nation has not yet been found.

Most States have laws or regulations that address specifically the use of pesticides to control nuisances in the aquatic environment. Some States regulate only the commercial applicators. Others regulate all chemical users. Before chemicals are applied to control any aquatic pest it is well to check with the appropriate State agency to ascertain the legality of the proposed chemical application and to obtain assistance in designing a control program for the particular problem. Very often the State authorities have a vast resource of data relating to the problem at hand and are in a position to provide technical assistance to the property owners in designing an appropriate abatement and control program that will not harm the overall aquatic ecosystem.

The application of the chemical to water involves certain hazards that must be understood and against which public rights must be protected. Factors that must be considered are the short- and long-range toxicity to all aquatic life, the deposition and possible accumulation of the chemical upon the lake bottom, the subsequent reaction upon the community of bottom organisms, the impact resulting from the destruction of too much biological growth at one time, and the possible disturbance or impairment of the general aquatic environment. It is essential that all pesticides including algicides and herbicides and related chemicals be applied in a manner fully consistent with the protection of the entire environment. When there is reasonable doubt regarding the environmental effects of the use of a given pesticide in a control program, no use should be made of the pesticide in question.

Animal Nuisances

Chemicals have been employed to control dense populations of nuisance animals. All such efforts have not been without their attendant problems. A classic example was the attempt to control midges in Clear Lake, California in 1949 when a chlorinated hydrocarbon insecticide DDD was applied. Following a second application of the insecticide in 1954 and a third application in 1957, western grebes were found dead along the lake shore. It then became evident that the persistent insecticide was being concentrated within the aquatic food web with the result that birds who feasted at the aquatic table received a resulting lethal dose. This unfortunate historic episode underscored dramatically the complexities associated with the application of a pesticide to the aquatic environment. It further stimulated a great deal of research directed toward finding less hazardous materials for the control of nuisance organisms.

Numerous chemical formulations have been tried for the control of various animal pests. At the present time there is no general method of chemical control that can be recommended.

Plate 62. Helicopter application of a granular herbicide.

The control of mosquitoes is a combination of mechanical and chemical means coupled with a routine and periodic surveillance of larval production. The mechanical means involves a destruction of areas for mosquito breeding and egg deposition. Containers that hold water after rainfall serve as excellent breeding sites and should be collected and removed from the landscape. The aquatic vegetation that provides cover for adults and egg deposition should be managed to reduce to a minimum the floatage and the amount of intersection line between plants and the water surface. Mosquito breeding areas that cannot or should not be drained may be treated with a surface film of oil or with the application of a larvicide following a determination that such procedures will not inflict irreversible damage to the environment. The periodic and continuing surveillance are essential parts of an adequate mosquito control program. Such surveillance involves a continual search for likely breeding areas and a periodic sampling of those areas to determine the mosquito larval population and development. Such surveillance usually is accompished by dipping a specified quantity of water from a suspected breeding area and counting the number of larvae that it contains and comparing the count so obtained with a count taken at a previous time. Trends in development can thus be noted and appropriate action taken.

Leeches are killed readily by exposure to a temperature of 20°F for a few hours. As water temperatures fall with the onset of winter, leeches become more and more sluggish and finally bury themselves in the mud or work their way beneath stones on the bottom of shallow water. Freezing of bottom muds accomplished by a rapid lowering of the water level after the first thin ice starts to form on the water has been effective in controlling leeches where such mechanical control measures can be practiced.

In general chemicals for leech controls have not proved successful, although chemicals such as copper sulfate will kill those leeches readily that are exposed to it. The principal difficulty with chemical controls is the fact that leeches are a very mobile organism and they dislike to remain in an area that has received chemical treatment for a sufficient length of time for them to receive a fatal dose. Weekly distributions of a slurry composed of ten pounds of copper sulfate and five pounds of copper carbonate or lime per acre of bathing area have shown some success as a temporary remedial leech control measure. The literature records further that the application of 100 pounds of powdered lime per acre per day in shallow waters has controlled leeches temporarily in localized beach areas. It must be appreciated that such dosage rates result in significant concentrations of the applied chemical in the water environment. The effects of such application, as well as alternative measures available, must be considered and evaluated prior to the instigation of a control program.

Swimmer's Itch Control

A substantial degree of control for the individual bather can be obtained by rubbing the body with a rough towel immediately on coming out of the water and before the water film has an opportunity to dry on the body surface. Such action will crush the cercariae before they have an opportunity to penetrate the skin. A freshwater shower taken immediately after leaving the water also is effective. The common practice of alternately swimming and sunbathing provides an excellent opportunity for a bather to receive a severe infection of swimmer's itch when infective cercariae are abundant in the water.

Chemical controls have been aimed toward virtual elimination of the intermediate host snail population within and around the bathing area. Lake waters with a total methyl orange alkalinity of 50 mg/l or greater have been treated successfully with a mixture of two pounds of copper sulfate plus one pound of copper carbonate for each 1,000 square feet of bottom area to be treated. Lake waters with a methyl orange alkalinity of less than 50 mg/l have been successfully treated with two pounds of copper carbonate per 1,000 square feet of bottom. It has been found nessary to apply such chemicals to at least 300 to

400 feet of lake frontage to a width of 200 feet or to the drop off whichever is less. Often it is desirable to treat up to 1,000 uninterrupted shoreline feet. Treatment should be conducted from the shoreline outward until the entire area is covered. One treatment is effective during a season and sometimes will maintain control throughout two swimming seasons.

The time of year that chemical treatment is undertaken is important because it involves the life cycle and habits of snails and fish. Studies indicate that very few young snails are infected with cercariae. Early in summer, numerous immature infections are present in the adult snails that have survived the winter. The majority of the cercariae complete their development and first begin to emerge from the snails in late June and early July. The infected snails in most cases continue to give off cercariae until their death in late summer or early fall. In the north central lake States the optimum time to apply chemical controls for swimmer's itch is between mid-June and July 4.

The theory of chemical application is to precipitate the maximum amount of copper on the bottom of the area receiving treatment where it will make direct contact with the snails. As the snails crawl over the treated area they adsorb the precipitated copper on the lake or pond bed until a lethal dose occurs.

For small scale operations very simple equipment will suffice to distribute the chemical mixture. An open-end, 50-gallon drum may be half-filled with water and placed in a suitable boat. Fifty pounds of copper sulfate (snow grade) should be added and stirred until dissolved. To this solution 25 pounds of copper carbonate is added slowly and stirred to make a suspension of the copper sulfate-copper carbonate mixture. A vigorous reaction takes place inside the drum with the addition of the copper carbonate and frothing is caused by the carbon dioxide produced. When all of the copper carbonate has been added and the chemical action has subsided the drum is filled with water and the solution is ready for use. It should be borne in mind that these chemicals are irritating to the mucous membranes of the human eye, nose, and throat. Prolonged exposure of the skin to this concentrated mixture should be avoided and precautions should be taken to protect anyone associated with the control measure.

The chemical solution from the drum is allowed to flow by gravity through a hose and pipe arrangement that will distribute the chemical solution evenly over the bottom of the area to be treated. Often an inverted "T" pipe with quarter inch holes drilled at three-inch intervals across the bottom portion of the pipe is a useful mechanism to distribute the chemical. The boat is propelled slowly back and forth so that the mixture can be distributed as evenly as possible. A drum filled with the 50 pounds of copper sulfate and 25 pounds of copper carbonate as described above is sufficient to treat 25,000 square feet of bathing area. Other methods of application include the trailing of a number of lengths of hose from the rear of the boat, which are weighted at the outlet end, to ensure introduction of the chemical solution directly on the bottom.

The chemical should be applied beneath the surface of the water directly over the snail beds when the water is very calm. Even slight ripples on the water's surface represent sufficient water movement to decrease the efficiency of the treatment. Applying the chemicals beneath the surface of the water concentrates the chemical within the treatment area and reduces its adverse effects on the ecology of the surrounding area. Areas to be treated should be marked carefully and subdivided into small sections to ensure even distribution of the calculated amount of chemical. Swimming should be prohibited for at least two hours after treatment to prevent undue chemical dispersion.

The chemicals applied to kill snails in the control of the swimmer's itch organism are, by nature, toxic to aquatic life. Any fish that may be trapped within the treated area or that are confined to live or bait traps will be killed. Usually the area requiring treatment for the control of swimmer's itch is small in relation to the total area of the water body in question thus the loss of fish food organisms as a result of the treatment will have a negligible effect upon the fishery. All precautions should be taken during the treatment operation to reduce to a minimum adverse effects upon the environment. The introductions of chemicals for this purpose usually are supervised by representatives of State governmental agencies to ensure minimal environmental harm.

21

Federal Programs for Pollution Abatement and Control

THE most comprehensive program ever enacted to clean up the Nation's waters became law on October 18, 1972. Known as the Federal Water Pollution Control Act Amendments of 1972, the new law mandates a sweeping Federal-State campaign to prevent, reduce and eliminate water pollution.

The law proclaims two general goals for the United States:

(1) To achieve wherever possible by July 1, 1983, water that is clean enough for swimming and other recreational uses, and clean enough for the protection and propagation of fish, shellfish and wildlife,

(2) and by 1985, to have no discharges of pollutants into the Nation's waters.

Those are goals. They reflect deep national concern about the condition of the Nation's waters and a strong commitment to end water pollution.

Enforcement

The River and Harbor Act of 1899 outlawed the discharge of pollutants other than municipal sewage into the navigable waters of the United States except by permit from the Army Corps of Engineers. The EPA cooperated closely with the Corps of Engineers in fulfilling the mandate of this Act. Applications for permit to discharge pollutants received a comprehensive evaluation within the Agency and, as a result, recommendations were made to the Corps of Engineers for action on the application. The recommendations (1) supported issuance of a permit in accordance with the application, (2) supported issuance of a conditional permit based upon a clear declaration by the applicant of an implementation program with acceptable dates for the control or treatment of pollution, and (3) supported a rejection of the application as presented.

While the Rivers and Harbors Act of 1899 had provided for the issuance of permits by the Corps of Engineers, the Federal Water

Pollution Control Act Amendments of 1972 have instituted a new permit program under EPA guidance and assistance that has shifted administration and enforcement to State governments. Under the new law, no discharge is permitted except as authorized by a discharge permit. This new amendment extends to previously exempt municipal discharges, so that all potential pollutants are now covered. While EPA issues guidelines for State permit programs, it retains a right to review a State-issued permit affecting another State's water resources.

Discharge permits must be consistent with effluent limitations, guidelines, and other requirements of the statute. They must be for periods no longer than five years, and may be terminated when there is a violation of a condition of the permit or when changed conditions dictate the need for further reduction of the permitted discharge. Similarly, EPA may withdraw approval of a State permit program if the agency determines the State has failed to fulfill the requirements of the Act.

The Federal Water Pollution Control Act provided for two enforcement mechanisms for pollution abatement. The first was a Federal conference; the second provided for a 180-day notice to violators. The enforcement conference was initiated with Federal, State and interstate water quality agency representatives and followed, if necessary, by a public hearing and finally court action. Conferences could be called by the Federal Government when water pollution from one State affected the health or welfare of persons in an adjoining State, or when requested by or with the consent of the Governor of a State, or if the shipment of shellfish was endangered. Following a conference, recommendations for pollution abatement were transmitted to the States by the EPA Administrator. If appropriate abatement actions were not taken, the Administrator could reconvene the conference or call a formal public hearing. If action was still not forthcoming the matter could be taken to the courts. Such conferences were an excellent mechanism for focusing public attention on polluters and the particular pollution problem. As a pure enforcement mechanism, they could become cumbersome. During 1972 the EPA initiated six new enforcement conferences and reconvened or convened additional sessions of seven conferences addressing areas on which initial action had begun previously.

The 180-day notification was a mechanism whereby violators of water quality standards were given an opportunity to comply with such standards voluntarily without legal action. If the violator failed to produce results acceptable to the Agency, court action could follow. In the first nine months of fiscal year 1972, EPA served 180-day notices on 26 industries and 56 municipalities.

Under the 1972 Amendments, EPA has the authority to enforce the provisions of the law through both administrative and judicial channels. When the Administrator finds a person to be in violation of a permit condition or other provision of the law, he must notify the polluter, and shall either issue an administrative order prohibiting further violation or pursue a judicial remedy for appropriate relief.

If the Administrator finds that violations within a State are widespread because of State inaction, he may so notify the State, and the Federal Government will assume enforcement responsibilities until the State can satisfy the Administrator that it will enforce the law.

In order to insure compliance with the law, EPA has been given broad inspection and monitoring powers. The agency has a right of entry to all effluent sources and authority to inspect records, data and information, monitoring equipment, and effluents. If a State develops similar procedures, the Administrator may transfer this authority to the State.

The Administrator may also bring suit if he finds that a particular pollution source presents an imminent and substantial danger to human health or danger to an individual's livelihood, such as the inability to market shellfish.

Research

The search for new answers to existing problems is an important facet of the Federal pollution control program. The research and demonstration program is aimed toward the development of new and innovative ideas for the treatment or control of water pollution that have wide applicability throughout the United States or within the industry or other field of research endeavor. Research is aimed toward fulfilling the needs of EPA's water pollution abatement programs. It is conducted in the EPA laboratories located in strategic regions throughout the Nation or through contracts primarily with industry or through grants primarily with universities, industries, States, and municipalities. Contract projects are funded entirely with Federal funds whereas grant projects require some level of matching support from the grantee.

Research currently is conducted in all program activities and includes pollution control technology for municipal, industrial, agricultural and mining activities, water quality control technology, waste treatment and ultimate disposal technology, water quality requirements and vessel wastes and oil spills control.

In January 1972 the Environmental Protection Agency sponsored publication of the Environmental Protection Research Catalog, Part I of the Catalog contains 897 pages and documents 5,488 project descriptions on air, water, solid waste management, pesticides, radiation and noise research. The Catalog contains ongoing research notices as of October 1971 that are concerned with environmental protection, pollution, and contamination. The listed research projects are supported largely by the Federal Government but conducted in academic institutions, State and local organizations laboratories, private foundations, professional associations, and industrial organizations, as well as Federal laboratories. Part II of the two part Catalog is a 1,445-page subject and investigator index to the project descriptions described in Part I.

Municipal Wastes

The greatest single category of Federal spending for environmental quality is for construction or improving waste treatment plants and interceptor sewers to carry wastes to the treatment plant. The Federal Water Pollution Control Act provides that grants may be made to States, municipalities, inter-municipal or interstate agencies to assist in the construction of waste treatment works that are needed to prevent the discharge of untreated or inadequately treated sewage or other wastes into any waters.

Based on 1968 municipal wastes facilities data, there are about 13,000 communities served with sewer systems. Of this number, 1500 discharge raw sewage only. Thus out of a sewered population of 140 million persons, 9.5 million or 6.8 percent discharge raw sewage to the receiving waterways. The vast majority (80 percent) of the sewage treatment installations provide a secondary level of treatment, which removes about 85 to 90 percent of the biochemical oxygen demand and 90 percent of the suspended solids. Nineteen percent of the sewered population in 1968 provided primary treatment only and the remainder provided various degrees of treatment including advanced waste treatment.

In addition to the need for new sewage treatment works to treat the raw or inadequately treated sewage from a substantial population within the United States, over 1,000 communities outgrow their treatment systems every year. Because of the continuing population growth in metropolitan areas and industrial expansion, there is a need to enlarge and upgrade many of the existing sewage treatment plants; particularly when problems of eutrophication occur in receiving waterways a need for phosphorus and sometimes nitrogen removal occurs.

The construction of a waste water treatment facility is only a part of the job to treat waste waters and prevent water pollution. The facilities must be operated in a continuing manner so that the plant will function in accordance with its design. Often waste treatment plant operators profit from training to maximize their operating skills. The EPA conducts a training program to fulfill this need. Short-term training courses are offered also for those who may be interested in enlarging their understanding of interrelationships within the aquatic environment, of chemical and biological investigative procedures to identify and define water pollution, and of laboratory analytical techniques.

An operations and maintenance program is conducted within the Federal Government to ensure that waste treatment facilities constructed with Federal funds can effectively and efficiently treat waste waters. A portion of this program is devoted to the publication of manuals for operating waste treatment installations.

A municipal waste water facilities inventory is maintained that describes each waste water treatment facility and gives information on its location, the community served, the waters to which it discharges, the type of treatment employed and the various operational components of the treatment facility, the population served by the unit, its designed capacity, the volume of waste flow, and any requirements for treatment plant improvements or needs.

Training

Water pollution control and water quality training grants are offered to expand the base and improve training in the causes, control and prevention of water pollution and to increase professional, scientific, and technical manpower. Grants are awarded to public and private agencies and educational institutions for the purpose of increasing the training of undergraduates in design, operation, and maintenance of waste water treatment works.

Water pollution control research fellowships are offered to increase the number of water pollution control specialists by supporting advanced specialized education and training of individuals. Qualified individuals with master's degrees are eligible for fellowships.

Training activities in State and local manpower development are directed toward designing and carrying out innovative and imaginative training projects which complement existing programs. Such activities provide advanced teacher training to those involved in conducting operator training programs and train operators in advanced waste treatment technology. State, local or district water pollution control agencies or a private non-profit institution designated by a public agency are eligible.

Industrial Wastes

The 1972 amendments changed the thrust of enforcement from water quality standards, regulating the amount of pollutants in a given body of water, to effluent limitations, regulating the amount of pollutants being discharged from particular point sources. Ambient water quality requirements can still dictate the amount of pollutants permitted for a discharger. The Administrator is directed to publish regulations by October 18, 1973, establishing guidelines for effluent limitations. These regulations shall identify the best practicable control technology available for various industrial categories. Factors for consideration are the cost-benefit of applying such technology, the age of equipment and facilities involved, and the process employed. Industrial discharges must meet these standards by July 1, 1977. Public treatment works must meet effluent limitations based on secondary treatment by this same date.

In addition, the Administrator shall identify the best available technology for preventing and reducing pollution. He is also responsible for identifying technology which would achieve the elimination of the discharge of pollutants. In both cases, he must take into account the factors enumerated above. Industrial dischargers are obliged to meet these standards by July 1, 1983, the same date given for achieving the national goal designed to protect fish, shellfish, wildlife and recreation. They must meet zero-discharge requirements if the Administrator determines that such a requirement is economically and technologically feasible. By July 1, 1983, public treatment works must use the best practicable waste treatment technology over the life of the works. New sources of discharge are required to use the best available technology as determined by the Administrator and published in the regulations. Zero-discharge by 1985 is a goal, not a requirement under the law.

Non-Point Source Wastes

Non-point source wastes that create water quality problems are more diffuse than those resulting from municipal and industrial activities and are characterized generally by wide-spread environmental degradation rather than easily noticed point-source impacts. Major sources causing appreciable adverse aquatic effects include animal feedlot and other wastes with resulting ammonia toxicity and dissolved oxygen problems from organic enrichment; irrigation return flows and tiled land run-off with increases in receiving water minerals, pesticides and nutrients; logging and general forestry practices with sediment load increases; rural sanitation facilities that foster infectious agents, allergens and taste and odor-producing substances; pesticides application and run-off with resulting toxicity and pesticides accumulation in the food web; construction site siltation; and general land run-off.

FEEDLOT WASTES

Wastes from feedlots are a key source of agricultural pollution. The total production of such wastes is approximately 1.7 billion tons annually. Agricultural waste sources are scattered throughout the Nation. Large cattle herds are fed in the Midwest, Southwest, and West; poultry in the South and in the Middle Atlantic States; and hogs in the Midwest and South. Run-off from animal feeding operations is 10 to 100 times more concentrated in oxygen-consuming organic materials than is raw domestic sewage.

Federal effort to attack this and other non-point source pollutional problems is in its infancy. The first task is to inventory the particular problem and define its pollutional nature and extent. On-site evaluations and comprehensive studies must be a part of this assessment to develop a quantitative knowledge of the problem. Following this, criteria and other guidelines will be developed to control the non-point source wastes and provide measures to effect control operations. A considerable base of information is available on the characteristics of the livestock feedlot waste problem and on control measures that appear to be feasible in decreasing water pollution from these sources.

FORESTRY AND LOGGING

The application of pesticides and fertilizers for high yield forest production, as well as log harvesting methods currently used, result in pesticide, nutrient, sediment, and organic waste contamination of receiving watercourses. Burning of harvested areas and log rafting cause related problems. Means for the prevention or control of these problems are required to enable forest-using agribusiness to meet water quality standards.

Tasks that must be completed include expansion of existing monitoring systems to evaluate more precisely the effects of forestry practices on water quality. Comprehensive studies of selected representative logging operations are needed to assess pollutional problems and to recommend specific control measures. Research is involved to develop means to prevent pollution from log rafting practices, and training will be necessary to ensure the dissemination of information and to promote the adoption of control methods.

IRRIGATION AND AGRICULTURAL RUN-OFF

The development of agriculture has grown along with population and industrial development. At first, land was cleared and plowed and barnyard manures were used as fertilizer. Precipitation was the sole moisture source. With the agricultural invasion of the arid West and the deterioration in the fertility of land settled earlier, irrigation systems were developed, inorganic fertilizers were applied, and the pesticide era began. With control technology in its infancy, results in serious water quality problems included inorganic chemical salts, nitrogen and phosphorus aquatic-vegetation-stimulating nutrients, sediments, and pesticides.

Many waters, including the Arkansas and Rio Grande Rivers are now unfit because of their salt content for public or industrial supply or irrigation. Violations of salinity water quality standards have been recorded on the San Joaquin River. The Colorado River is a noteworthy waterway with its salt problems. The cost of losses from nutrient-stimulated aquatic plant growths and their control in 17 western States has been estimated at $14 million annually. Methods are needed to prevent and control 1 billion tons of sediment and run-off and pollution from 700 million pounds of pesticides and 10 million tons of fertilizers that reach the watercourses each year.

On January 14, 1972, the EPA promulgated a policy on the control of nutrient run-off from agricultural lands. In this policy it was noted that management of agricultural nutrients will require appropriate limitation of erosion and sediment run-off, the effective use of applied fertilizers by the plants, the application of fertilizers under the right climatic and proper growth conditions, and the retention of animal waste on the land. The policy stated that animal wastes should not be applied to farm lands and under adverse soil or weather conditions except when planned methods will ensure that they remain on the land. Wastes should be stored in designated structures until they can be incorporated into the soil. Watering and feeding points should be established away from waterways along with the establishment of run-off and erosion control measures to prevent the concentration of animal wastes in the vicinity of streams. When a high density of animals is created through confinement, fencing of the streams traversing such areas should be used as a means of preventing water pollution by the wastes of the confined animals and the physical destruction of the stream beds and banks.

The policy was developed to promote the voluntary use of the stated guidelines in a fertilizer program for individual farms and to encourage such use through a strong effort by the presently available educational programs of Federal, State, and local agencies and educational institutions, and through technical assistance.

PESTICIDES

Pesticides include a wide variety of chemical compounds to control undesired life forms that threaten man, his possessions, and portions of the natural environment that he values. Over 900 pesticidal chemicals are formulated into more than 60,000 preparations in the United States. Production and sale of synthetic organic pesticides reached 1.2 billion pounds in 1968 and more than half of those were used in farming.

The Water Quality Improvement Act of 1970 mandated that the EPA conduct a study and investigation of methods to control the release of pesticides into the environment and include an examination of the persistency of pesticides in the water environment and alternatives thereto. A report addressing the effects of pesticide pollution, the persistency and degradation of pesticides, alternatives to pesticide uses and other related information has been prepared for submission to the Congress and will be available for distribution soon.

CONSTRUCTION SITE SILTATION

Man's land development activities have upset drastically the natural and necessary geologic processes of sedimentation by greatly accelerating erosion. Deposition of excess quantities of sediments pollutes downstream waters and damages land.

The energy responsible for erosion is provided by falling rain and flowing run-off water. One inch of precipitation falling on one acre of exposed soil weighs 110 tons. Approximately 10 percent of the sediment quantity reaching the rivers of this country each year is contributed by erosion from lands undergoing highway construction or land development. Sediment yields in streams flowing from urbanized drainage basins vary from approximately 200 to 500 tons per square mile each year. In contrast the urbanized areas have a sediment yield of from 1,000 to 100,000 tons per year.

The technical capability of controlling erosion and sediment deposition is available. It involves protection of disturbed soils from the energy of falling rain and flowing run-off water by installing protective covers, controlling run-off and trapping sediments in transport. The EPA in September 1971 published a bulletin on the "Control of Erosion and Sediment Deposition from Construction of Highways and Land Development." The purpose of this publication was to define the nature and extent of the problem and to suggest erosion and sediment control measures that can be employed not only to protect the lands but also to protect the receiving waterways from sediments that otherwise would be washed from the lands. In addition to filling in receiving waterways and covering waterway bed habitats, sediments carry adsorbed nutrients, pesticides, and other materials that may have a deleterious effect on the receiving environment.

The Subsurface Environment

Actions that the EPA can take relating to the subsurface environment include technical assistance, research, and enforcement activity.

As a part of its technical assistance program, the Agency published a selected annotated bibliography on subsurface water pollution in March 1972. This bibliography represented published summaries of research reports as abstracted and indexed in the semi-monthly journal "Selected Water Resources Abstracts." The three-part bibliography resulted from a search of nearly 34,000 items from October 1968 through December 1971. Part I considers pollution associated with subsurface waste injection. Part II addresses pollution associated with saline water intrusion. Part III considers pollution associated from percolation from surface sources.

Vessel Wastes

The Water Quality Improvement Act of 1970 mandated the Environmental Protection Agency to promulgate standards of performance for marine sanitation devices to prevent the discharge of untreated or inadequately treated sewage into or upon the navigable waters of the United States from vessels with installed toilet facilities. In June 1972 EPA published final standards laying out a number of steps to curtail discharges of vessel sewage into U. S. navigable waters. These standards pertain to about 500,000 recreational boats, 14,000 fishing vessels, 6,000 tow and tug boats, 1500 Corps of Engineers' ships, boats and crafts, 700 U. S. Navy ships, 700 U. S. commercial vessels, and an unknown number of foreign flag ships. According to the law, the standards become effective for new vessels two years after promulgation and for existing vessels five years after promulgation.

The Coast Guard has regulatory authority concerning the implementation of marine sanitation device standards and may distinguish among classes, types, and sizes of vessels, as well as between new and existing vessels and may waive applicability of standards and regulations as necessary or appropriate.

The EPA standards are implemented with the promulgation of a Coast Guard regulation governing the design, construction, installation, and operation of any marine sanitation devices onboard vessels. The Coast Guard is mandated to certify a marine sanitation device that shall be deemed to be in conformity with the EPA standards. Federal vessel pollution control regulations preempt any State statutes or regulations pertaining to the control of human body wastes from vessels on their effective dates.

The Federal standard provides that marine sanitation devices installed on vessels shall be designed and operated to prevent the overboard discharge of sewage, treated or untreated, or of any waste derived from sewage, into the navigable waters of the United States. To provide for some vessel pollution control prior to the legal effective date of the regulation, incentive provisions were provided for owners and operators of existing vessels to install currently available vessel waste treatment devices. Any existing vessel equipped with a marine sanitation device on which is installed a treatment system that will reduce fecal coliform bacteria to no more than 1000 per 100 milliliters and prevent the discharge of an effluent with visible floating solids shall not be required to comply with the no-discharge provision of the regulation for a specified period of time depending upon the date of installation. If the treatment device is installed within three years after the promulgation of the regulation the treatment device may be used as long as it remains operable. If such a device is installed after three years from the date of initial promulgation of the implementing Coast Guard regulations but before the effective date of the Federal regulation, the device may be used for a period of three years following the regulation's effective date. There is a provision in the regulation whereby a State may apply and obtain a regulation completely prohibiting discharge from a vessel of any sewage into particular waters of the State or specified portions thereof where a complete prohibition is required by applicable water quality standards.

Water Quality Standards

The Water Quality Act of 1965 authorized the establishment and enforcement of water quality standards for interstate waters including coastal waters. This piece of legislation has been a keystone of America's clean water program. In developing water quality standards, the States initially held public hearings to define particular water uses for the States' interstate streams. Such water uses included domestic water supply, recreation, fish and other wildlife, agricultural, and industrial. Following the designation of water uses for particular stream reaches, water quality criteria were established by the States to ensure that the water would be of a quality to support the designated use. In addition, an implementation program was established that outlined the pollution abatement measures that would be required to meet the designated criteria. The States then submitted their individual water quality standards to the Federal Government and, upon approval, the standards became Federal-State water quality standards. The first responsibility for implementing and enforcing the water quality standards rests with the State. If the State does not act on a violation, however, Federal enforcement action can ensue.

The criteria that were adopted to protect interstate and coastal waters varied to some extent among the several States. In general the criteria specified a minimum water quality applicable in all places at all times. Minimal water quality criteria would prevent the discharge of materials attributable to pollutional discharges that would float as unsightly objects, settle to form putrescent sludge deposits, impart tastes or odors to water or fish or other organisms, result in a toxic action to fish or other water users, or serve to stimulate the growth of undesirable biota. Generally specific numerical criteria were recorded for the water temperature, dissolved oxygen, pH, and often other water quality constituents. Specific criteria for nitrogen and phosphorus were designated for some of the major lake water resources.

The 1972 Amendments provide that water quality standards shall be developed and apply to all interstate and intrastate navigable waters. In addition to setting water quality standards, where effluent limitations will not be stringent enough to meet water quality standards, the States are required to establish maximum daily loads of pollutants permitted in the waters that will allow the propagation of fish and wildlife. A similar assessment must be made for thermal discharges. States are also required to develop a continuing planning process which is able to deal with the changing patterns of water pollution within the State. Beginning in 1975, the States must submit to Congress and EPA annual reports with an inventory of all point sources of discharge, an assessment of existing water quality and projected goals, and proposals of programs for nonpoint source control. EPA must submit a similar report to Congress on January 1, 1974.

TOXIC AND PRETREATMENT EFFLUENT STANDARDS

As part of the comprehensive authority vested in the Administrator, he is directed to publish a list of toxic pollutants and effluent limitations for these substances. Such limitations may constitute an absolute prohibition against discharging. Additionally, the Administrator must publish pretreatment standards requiring any industry discharging into a municipal sewage treatment plant to pretreat its effluent so that it does not interfere with the operation of the plant or pass through the plant untreated or without adequate treatment.

OCEAN DUMPING

The new ocean dumping legislation, the Marine Protection, Research and Sanctuaries Act of 1972, passed by the 92nd Congress and signed into law by the President on October 27, 1972, declares it to be the national policy "to regulate the dumping of all types of materials into ocean waters and to prevent or strictly limit the dumping into ocean waters of any material which would adversely affect human health, welfare or amenities, or the marine environment, ecological systems or economic potentialities." Currently, criteria are being developed to control this source of pollution.

Other Activities

There are a host of additional activities associated with the control of water pollution. There is a national multi-agency oil and hazardous materials contingency plan that provides the organizational and communications mechanism for combining Federal, State, and local efforts into a coordinated response to control and clean up spills of oil and hazardous materials. A technical assistance program is available to help States solve pollution problems. Field studies can be undertaken under this program to define an environmental problem and proffer recommendations for its control or for environmental enhancement.

A significant involvement of the Environmental Protection Agency is in planning activities for pollution control. Clean water will be achieved only by systematically controlling pollution in entire river basins. Furthermore, we must be sure that actions taken today will be adequate to meet the needs of tomorrow. Thus, long-range plans are made with provisions for future growth of waste loads, population, industry, and water uses.

Criteria are currently being developed to define a polluted dredge spoil that would be unacceptable for open-water disposal. Information is being collected on the number and extent of bathing beaches that are closed annually because of pollution, as well as the number of shellfish areas that are closed because of pollution. When data of this type are compared for one year with those of another, an index of accomplishment or nonaccomplishment in the fight against water pollution control is provided.

Water quality data are collected on a number of fixed water quality stations throughout the Nation. These data are stored on computer tape in such a manner that it will be possible to compare the water quality in a particular location from which samples have been collected with the water quality standards for that reach of waterway. Additional data that will be available for the same location will include information on municipal and other point sources of wastes, a resume of the implementation program to abate pollution from indicated sources and a designation indicating the violation of any time frame within the implementation program.

References Cited

Allen, M. B. 1955. General Features of Algae Growth in Sewage Oxidation Ponds. California State Water Pollution Control Board. Sacramento. Publication No. 13, pp. 11-34.

Anderson, R. R., R. C. Brown and R. D. Rappleye. 1965. Mineral Composition of Eurasian Water Milfoil. *Myriophyllum spicatum* L., Chesapeake Sci., 6(1):68-72.

Anon. 1946. Schistosomiasis the Blood Fluke Disease. U. S. Public Health Service. Atlanta, Georgia. 19 pp.

Anon. 1953 (Rev.). Fiber Analyses of Paper and Paperboard. T401 m-53. Technical Association of the Pulp and Paper Industry, 155 East 44th St., New York 17, New York.

Anon. 1962. Economic Studies of Outdoor Recreation. Outdoor Recreation Resources Review Commission. Washintgon, D. C. Study Report 24. 166 pp.

Anon. 1967. Surface Mining and Our Environment. A Special Report to the Nation. U. S. Dept. of the Interior. Washington, D. C., 124 pp.

Anon. 1968. Water Quality Criteria. Report of the National Technical Advisory Committee to the Secretary of the Interior. Fed. Water Pollution Control Administration. U. S. Department of the Interior. Washington, D. C., 234 pp.

Anon. 1971. Stream Faunal Recovery after Manganese Strip Mine Reclamation. Environmental Protection Agency, Water Pollution Control Research Series 18050 DOH 06/71.

Ballinger, D. G. and D. G. McKee. 1971. Chemical Characteristics of Bottom Sediments. Journal Water Pollution Control Federation 43(2):216-227.

Beard, H. R. 1926. Nutritive Value of Fish and Shellfish. Report U. S. Commissioner of Fisheries for 1925, 501-552.

Belding, D. L. 1942. Textbook of Clinical Parasitology. D. Appleton-Century Co., New York, 888 pp.

Birge, E. A. and C. Juday. 1911. The Inland Lakes of Wisconsin. The Dissolved Gases of the Water and their Biological Significance. Wis. Geol. Nat. Hist. Sur. Bull. 22, Scientific Series 7. 259 pp.

Birge, E. A. and C. Juday. 1922. The Inland Lakes of Wisconsin. The Plankton. I. Its Quantity and Chemical Composition. Wis. Geol. and Natural History Bull. No. 64. Scientific Series No. 13. 222 pp.

Black, C. S. 1929. Chemical Analyses of Lake Deposits. Trans. Wis. Acad. Sci., Arts and Letters, 24:127-133.

Borgstrom, G. (Ed.). 1961. Fish as Food. Academic Press, Inc. New York, 725 pp.

Borutsky, E. V. 1939. Dynamics of the Total Benthic Biomass in the Profundal of Lake Beloie. Proc. Kossino Limn. Sta. of the Hydrometeorological Service. U.S.S.R. 22:196-218. Trans. by M. Ovchynnyk, edited by R. C. Ball and F. F. Hooper.

Brackett, S. 1941. Schistosome Dermatitis and Its Distribution. A Symposium on Hydrobiology. University of Wisconsin Press. Madison. pp. 360-378.

Brinkhurst, R. O. 1964. Observations on the Recovery of a British River from Gross Organic Pollution. Hydrobiologia, 25:9-51.

Brown, F. 1942. The Microscopy of Mammalian Hair for Anthropologists. Proceedings of the American Philosophical Society, 85(3):250-274.

Bush, A. F. and S. F. Mulford. 1954. Studies of Waste Water Reclamation and Utilization. California State Water Pollution Control Bd., Sacramento. Publication No. 9.

Carpenter, C. H. et al. 1963. Papermaking Fibers. A Photomicrographic Atlas of Woody, Non-woody, and Man-made Fibers Used in Papermaking. State University College of Forestry at Syracuse University, Syracuse, New York.

Chandler, R. F., Jr. 1943. Amount and Mineral Nutrient Content of Freshly Fallen Needle Litter of Some Northeastern Conifers. Soil Sci. Soc. Amer. Proc., 8.

Cooke, W. B. 1956. Colonization of Artificial Bare Areas by Microorganisms. Botanical Review, 22(9):613-638.

Cort, W. W. 1928. Schistosome Dermatitis in the United States (Michigan). Jour. Am. Medical Association, 90:1027-1029.

Cort, W. W. 1950. Studies on Schistosome Dermatitis. XI. Status of Knowledge after more than Twenty Years. Am. Jour. Hygiene, 52(3):251-307.

Creitz, G. I. and F. A. Richards. 1955. The Estimation and Characterization of Plankton Populations by Pigment Analysis III. A Note on the Use of "Millipore" Membrane Filters in the Estimation of Plankton Pigments. Jour. Marine Res. 14(3):211-216.

Dineen, C. F. 1953. An Ecological Study of a Minnesota Pond. Amer. Midland Naturalist. 50(2):349-356.

Donahue, R. L. 1961. Our Soils and Their Management. The Interstate Printers and Publishers, Inc., Danville, Ill., 568 pp.

Ekman, S. 1911. Neue Apparate zur Qualitativen und Quantitativen Erforschung der Bodenfauna der Seen. Intl. Rev. Hydrobiol., 7:164-204.

Engelbrecht, R. S. and J. J. Morgan. 1961. Land Drainage as a Source of Phosphorus in Illinois Surface Waters. Algae and Metropolitan Wastes. U. S. Public Health Service. SEC TR W61-3.74.

Eyles, D. E. and J. L. Robertson. 1944. A Guide and Key to the Aquatic Plants of the Southeastern United States. U. S. Public Health Service Bulletin No. 286. 151 pp.

Fassett, N. C. 1960. (Revised Edition) A Manual of Aquatic Plants. University of Wisconsin Press. Madison. 405 pp.

Finger, J. H. and T. A. Wastler. 1969. Organic Carbon-Organic Nitrogen Ratios of Sediments in a Polluted Estuary. Jour. Water Poll. Control Fed., 41(2):R101-109.

Fitch, C. P., et al. 1934. "Water Bloom" as a Cause of Poisoning in Domestic Animals. Cornell Veterinarian. 24(1):30-39.

Forest, H. S. 1954. Handbook of Algae. University of Tennessee, Knoxville. 467 pp.

Frantz, T. C. and A. J. Cordone. 1967. Observations on Deepwater Plants in Lake Tahoe, California and Nevada. Ecology 48(5):709-714.

Fremling, C. R. 1960. Biology of a Large Mayfly, *Hexagenia bilineata* (Say), of the Upper Mississippi River. Agricultural and Home Economics Exp. Sta., Iowa State Univ. of Science and Technology. Ames. Research Bull. No. 482, 842-851.

Gaufin, A. R. and C. M. Tarzwell. 1955. Environmental Changes in a Polluted Stream During Winter. The American Midland Naturalist. 54(1):77-88.

Gerloff, G. C. and F. Skoog. 1954. Cell Content of Nitrogen and Phosphorus as a Measure of their Availability for Growth of *Microcystis aeruginosa*. Ecology. 35(3):348-353.

Goldman, C. R. 1960. Primary Productivity and Limiting Factors in Three Lakes of the Alaska Peninsula. Ecological Monographs 30:207-230.

Gorham, P. R. 1964. Toxic Algae as a Public Health Hazard. Jour. Amer. Water Works Association, 56(11):1481-1488.

Grzenda, A. R. and M. L. Brehmer. 1960. A Quantitative Method for the Collection and Measurement of Stream Periphyton. Limnology and Oceanography. 5(2):190-194.

Harper, H. J. and H. R. Daniel. 1939. Chemical Composition of Certain Aquatic Plants. Botanical Gazette, 96:186.

Hester, F. E. and J. S. Dendy. 1962. A Multiple-Plate Sampler for Aquatic Macroinvertebrates. Trans. Amer. Fish. Soc., 91(4):420-421.

Hopkins, C. L., H. V. Browerton and H. J. W. McGrath. 1966. The Effect on a Stream Fauna of an Aerial Application of DDT Prills to Pasture Land. New Zealand Journal of Science, 9:236-248.

Hutchinson, G. E. 1957. A Treatise on Limnology. John Wiley and Sons. New York, 1015 pp.

Ingalls, R. L., et al. 1950. Nutritive Value of Fish from Michigan Waters. Michigan State College Agr. Exp. Sta. Bull. No. 219. 24 pp.

Juday, C. and E. A. Birge. 1931. A Second Report on the Phosphorus Content of Wisconsin Lake Waters. Trans. Wis. Acad. Sci., Arts and Letters, 26:353.

Juday, C., E. A. Birge, and V. W. Meloche. 1941. Chemical Analysis of the Bottom Deposits of Wisconsin Lakes. II. Second Report. Trans. Wis. Acad. Sci., Arts and Letters, 33:99-114.

Keup, L. E. 1968. Phosphorus in Flowing Waters. Water Research. Pergamon Press, 2:373-386.

Lackey, J. B. 1938. The Manipulation and Counting of River Plankton and Changes in Some Organisms Due to Formalin Preservation. Public Health Reports, 53(47): 2080-2093.

Love, R. M., J. A. Lovern, and N. R. Jones. 1959. The Chemical Composition of Fish Tissues. Dept. Scientific and Ind. Res. Special Report No. 69, H.M.S. Stationery Office. London, 62 pp.

Lueschow, L. A. and K. M. Mackenthun. 1962. Detection and Enumeration of Iron Bacteria in Municipal Water Supplies. Jour. Amer. Water Works Association, 54(6):751-756.

Lund, J. W. G. and J. F. Talling. 1957. Botanical Limnological Methods with Special Reference to the Algae. Botanical Review, 23(8-9):489-583.

Mackenthun, K. M. and W. M. Ingram. 1967. Biological Associated Problems in Freshwater Environments. Their Identification, Investigation and Control. U. S. Dept. of the Interior. Fed. Water Poll. Control Administration, 287 pp.

Mackenthun, K. M., L. E. Keup, and R. K. Stewart. 1968. Nutrients and Algae in Lake Sebasticook, Maine. Jour. Water Poll. Control Fed., 40(2):R72-R81.

Martin, J. B., Jr., B. N. Bradford, and H. G. Kennedy. 1969. Factors Affecting the Growth of *Najas* in Pickwick Reservoir. National Fertilizer Development Center, Tennessee Valley Authority, Muscle Shoals, Alabama. Doc. No. F70 ACD 2.

Martin, A. C., R. C. Erickson and J. H. Steenis. 1957. Improving Duck Marshes by Weed Control. Fish and Wildlife Service, U. S. Department of the Interior, Circular No. 19 (Revised), 60 pp.

Mason, H. L. 1957. A Flora of the Marshes of California. University of California Press, Berkeley, 878 pp.

Mathiak, H. A. 1938. A Key to Hairs of the Mammals of Southern Michigan. The Journal of Wildlife Management, 2(4):251-268.

McGauhey, P. H., et al. 1963. Comprehensive Study on Protection of Water Resources of Lake Tahoe Basin Through Controlled Waste Disposal. Prepared for the Bd. of Directors, Lake Tahoe Area Council, Al Tahoe, 157 pp.

McRoy, C. P. and R. J. Barsdate. 1970. Phosphate Absorption in Eelgrass. Limnology and Oceanography 15(1):6-13.

Metzler, D. F., et al. 1958. Emergency Use of Reclaimed Water for Potable Supply at Chanute, Kansas. Jour. Amer. Water Works Association, 50(8):1021.

Morgan, A. H. 1930. Field Book of Ponds and Streams. G. P. Putnam's Sons, New York. 448 pp.

Moyle, J. B. 1940. A Biological Survey of the Upper Mississippi River System (in Minnesota.) Minn. Dept. Cons. Fish. Inv. Report No. 10, 69 pp.

Muenscher, W. C. 1944. Aquatic Plants of the United States. Comstock Publishing Co., Inc., New York, 374 pp.

Neil, J. H. 1958. Nature of Growth in a Report on Algae, *Cladophora*. Report of Ontario Water Resources Commission, 3-7.

Oswald, W. J. 1960. Metropolitan Wastes and Algal Nutrition. Algae and Metropolitan Wastes, U. S. Public Health Service, SEC. TR W61-3, 88-95.

Owen, R. 1953. Removal of Phosphorus from Sewage Plant Effluent with Lime. Jour. Water Poll. Control Fed., 25(5):548.

Palmer, C. M. 1959. Algae in Water Supplies. U. S. Public Health Service Publication No. 657. 88 pp.

Paloumpis, A. A. and W. C. Starrett. 1960. An Ecological Study of Benthic Organisms in Three Illinois River Flood Plain Lakes. Amer. Midland Naturalist, 64(2):406.

Patrick, R., M. H. Hohn, and J. H. Wallace. 1954. A New Method for Determining the Pattern of the Diatom Flora. Notulae Naturae 259:1-12.

Patrick, R. and C. W. Reimer. 1966. The Diatoms of the United States. Vol. 1. The Academy of Natural Sciences of Philadelphia. Monograph No. 13. 688 pp.

Petersen, C. G. J. 1911. Valuation of the Sea. Danish Biol. Sta. Report 1. 20:1-76.

Porterfield, J. D. 1952. Water Pollution: Its Effect on the Public Health. Proc. First Ohio Water Clinic. Ohio State University Engineering Series Bull. No. 147. Columbus. pp 34-39.

Prescott, G. W. 1951. Algae of the Western Great Lakes Area. Cranbrook Inst. Sci., Bloomfield Hills, Mich. 946 pp.

Prescott, G. W. 1954. How to Know the Fresh Water Algae. Wm. C. Brown Co. Dubuque, Iowa. 211 pp.

Prescott, G. W. 1960. Biological Disturbances Resulting from Algal Populations in Standing Waters. The Ecology of Algae. Spec. Publ. No. 2. Pymatuning Laboratory of Field Biology. University of Pittsburgh. pp. 22-37 (1959).

Richards, F. A. with T. G. Thompson. 1952. The Estimation and Characterization of Plankton Populations by Pigment Analyses II. A Spectrophotometric Method for the Estimation of Plankton Pigments. Jour. Marine Res., 11(2):156-172.

Rickett, H. W. 1922. A Quantitative Study of the Larger Aquatic Plants of Lake Mendota. Trans. Wis. Acad. Sci., Arts and Letters 20:501-522.

Rickett, H. W. 1924. A Quantitative Study of the Larger Aquatic Plants of Green Lake, Wisconsin. Trans. Wis. Acad. Sci., Arts and Letters, 21:381-414.

Ross, H. H. 1947. The Mosquitoes of Illinois. Ill. Natural History Survey Bull. 24(1):96 pp.

Rudolfs, W. and H. Heukelekian. 1931. Effect of Sunlight and Green Organisms on Reaeration of Streams. Industrial and Engineering Chemistry, 23, pp. 75-78.

Sanderson, W. W. 1953. Studies of the Character and Treatment of Wastes from Duck Farms. Proc. 8th Ind. Waste Conf., Purdue Univ. Ext. Ser., 83:170-176.

Sawyer, C. N. 1947. Fertilization of Lakes by Agricultural and Urban Drainage. Jour. New England Water Works Assn. 61:109.

Sawyer, C. N. 1965. Problem of Phosphorus in Water Supplies. Jour. Amer. Water Work Association. 57(11):1431.

Sawyer, C. N., J. B. Lackey, and R. T. Lenz. 1945. An Investigation of the Odor Nuisances Occurring in the Madison Lakes, Particularly Monona, Waubesa, and Kegonsa from July 1942-44. Report of Governor's Committee. Madison, 2 vols. (Mimeo.)

Schuette, H. A. and H. Alder. 1928. Notes on the Chemical Composition of Some of the Larger Aquatic Plants of Lake Mendota. II. *Vallisneria* and *Potamogeton*. Trans. Wis. Acad. Sci., Arts and Letters 23:249-254.

Schuette, H. A. and H. Alder. 1929. Notes on the Chemical Composition of Some of the Larger Aquatic Plants of Lake Mendota. III. *Castalia odorata* and *Najas flexilis*. Trans. Wis. Acad. Sci., Arts and Letters, 24:135-139.

Sladecek, V. and A. Sladeckova. 1964. Determination of the Periphyton Production by Means of the Glass Slide Method. Hydrobiologia. XXIII(Fasc. 1-2):125-158.

Sladeckova, A. 1962. Limnological Investigation Methods for the Periphyton ("Aufwuchs") Community. Botanical Review. 28(2):286-350.

Smith, G. M. 1950. The Fresh Water Algae of the United States. McGraw Hill Book Co., New York. 719 pp.

STUART, T. A. 1953. Spawning, Migration, Reproduction and Young Stages of Loch Trout (*Salmo trutta* L.). Scottish Home Dept., Freshwater and Salmon Fisheries Research. No. 5. 39 pp.

SURBER, E. W. 1936. Rainbow Trout and Bottom Fauna Production in One Mile of Stream. Trans. Amer. Fish. Soc., 66:193-202.

SWINGLE, H. W. 1950. Relationships and Dynamics of Balanced and Unbalanced Fish Populations. Agr. Exp. Sta., Ala. Polytechnic Inst., Auburn. Bull. No. 274. 1-74.

SYLVESTER, R. O. 1961. Nutrient Content of Drainage Water from Forested, Urban and Agricultural Areas. Algae and Metropolitan Wastes. U. S. Public Health Service. SEC TR W61-3. 80.

SYLVESTER, R. O. and G. C. ANDERSON. 1964. A Lake's Response to its Environment. Jour. San. Eng. Div., Proc. Amer. Soc. Civil Engr., 90(SA1):1-22.

TAFT, C. E. 1961. A Revised Key for the Field Identification of Some Genera of Algae. Turtox News, 39(4):98-103.

THOMAS, N. A. 1968. Personal Communication.

TIFFANY, L. H. and M. E. BRITTON. 1952. The Algae of Illinois. University of Chicago Press, Chicago. 407 pp.

WEIBEL, S. R. 1965. Personal Communication.

WILSON, J. N. 1957. Effects of Turbidity and Silt on Aquatic Life. In: Biological Problems in Water Pollution. U. S. Department of Health, Education, and Welfare. Robert A. Taft Sanitary Engineering Center. pp. 235-239.

Glossary

ABSORPTION—The taking up of one substance into the body of another.

ACID MINE DRAINAGE—Drainage from certain mines of water containing minerals and having a low pH. The low pH is commonly caused by oxidation of iron sulfide to sulfuric acid. Mine water usually contains a high concentration of iron.

ACTINOMYCETES—Mold-like bacteria involved in the decomposition of organic matter and may be responsible for tastes and odors in water supplies.

ADSORPTION—The adherence of a gas, liquid, or dissolved material on the surface of a solid.

AEROBIC ORGANISM—An organism that thrives in the presence of oxygen.

AESTHETIC INSULTS—A degradation of beauty through arrogant mistreatment.

ALGICIDE—A specific chemical highly toxic to algae. Algicides are often applied to water to control nuisance algal blooms.

AMOEBA—A genus of unicellular protozoan organisms of microscopic size existing in nature in large numbers; many living as parasites; some species pathogenic to man.

ANAEROBIC ORGANISM—A microorganism that thrives best, or only, when deprived of oxygen.

ARTIFICIAL SUBSTRATE—A device placed in the water for a period extending to a few weeks that provides living spaces for a multiplicity of drifting and natural-born organisms that would not otherwise be at the particular spot because of limiting physical habitat. Examples of artificial substrates include glass slides, tiles, bricks, wooden shingles, concrete blocks, multiplate plate samplers, and brush boxes.

BENTHIC REGION—The bottom of all waters; the substratum that supports the benthos.

Benthos—Bottom-dwelling organisms. The benthos comprise: (1) sessile animals such as the sponges, barnacles, mussels, and oysters, some of the worms, and many attached algae; (2) creeping forms, such as snails and flatworms; and (3) burrowing forms, which include most clams and worms.

Biochemical Oxygen Demand (B.O.D.)—A measure of the quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. In general, a high B.O.D. indicates the presence of a large amount of organic material. It is normal to find a B.O.D. of 2 to 5 mg/l in river waters receiving natural drainage.

Biodegradable—The destruction or mineralization of either natural or synthetic organic materials by the microorganisms of soils, waters, or wastewater treatment systems.

Biomass—The weight of all life in a specified unit of environment, for example, a square foot of stream bottom. An expression dealing with the total mass or weight of a given population, both plant and animal.

Black Fly Larvae (Simuliidae)—Aquatic larvae that produce a silk-like thread with which they anchor themselves to objects in swift waters. With a pair of fan-shaped structures, a larva of this type produces a current of water toward its mouth and from this water ingests smaller organisms. The adults are terrestrial; females feed on the blood of higher animals.

Bloodworms (Chironomidae)—Cylindrical elongated midge larvae with pairs of prolegs on both the first thoracic and last abdominal segments. Although many species are blood-red in color, some are pale yellowish, yellowish red, brownish, pale greenish yellow, and green. Most feed on diatoms, algae, tissues of aquatic plants, decaying organic matter, and plankton. Some are associated with rich organic deposits. Midge larvae are important as food for fishes.

Bloom—A readily visible concentrated growth or aggregation of plankton (plant and animal).

Coliform Bacteria—A group of bacteria predominantly inhabiting the intestines of man or animals but also occasionally found elsewhere. Fecal coliform bacteria are those organisms associated with the intestine of warm-blooded animals that are used commonly to indicate the presence of fecal material and the potential presence of organisms capable of causing disease in man.

Damselfly Nymphs (Odonata)—The immature damselfly. This aquatic insect nymph has an enormous grasping lower jaw and three flat leaf-like gill plates that project from the posterior of the abdomen. Nymphs live most of their lives searching for food among submerged plants in still water; a few cling to plants near the current's edge; and a very few cling to rocks in flowing water. The carnivorous adults capture flying insects on the wing.

Dermatitis—An inflammation of the skin. One type may be caused by the penetration, beneath the skin, of a cercaria found in water; this form of dermatitis is commonly called "swimmer's itch."

Diatometer—An apparatus that holds microscopic slides in the water. It is held in place by means of floats and an anchor. Living diatoms, by means of their thin gelatinous coating, become attached to the glass slides. The slides are removed from the diatometer, at intervals generally of 14 days, dried and shipped to the laboratory for study, identification, and enumeration.

Diatoms—Organisms closely associated with algae that are characterized by the presence of silica in the cell walls which are sculptured with striae and other markings, and by the presence of a brown pigment associated with the chlorophyll.

Dragonfly Nymph (Odonata)—The immature dragonfly. This aquatic insect nymph has gills on the inner walls of its rectal respiratory chamber. It has an enormous grasping lower jaw that it can extend forward to a distance several times the length of its head. Although many of these nymphs climb among aquatic plants, most sprawl in the mud where they lie in ambush to await their prey. The carnivorous adults capture lesser insects on the wing.

Ecology—The branch of biology that deals with the mutual relations of living organisms and their environments, and the relations of organisms to each other.

Ecosystem—The functioning together of the biological community and the non-living environment.

Epilimnion—That region of a body of water that extends from the surface to the thermocline and does not have a permanent temperature stratification.

Epithelial Layer—Cellular tissue covering all the free body surfaces, cutaneous, mucous and serous, including the glands and other structures derived therefrom.

Eutrophic Waters—Waters with a good supply of nutrients; they may support rich organic production, such as algal blooms.

Eutrophication—The intentional or unintentional enrichment of water.

Fall Overturn—A physical phenomenon that may take place in a body of water during the early autumn. The sequence of events leading to fall overturn include: (1) cooling of surface waters, (2) density change in surface waters producing convection currents from top to bottom, (3) circulation of the total water volume by wind action, and (4) vertical temperature equality, 4°C. The overturn results in a uniformity of the physical and chemical properties of the water.

Floc—A small, light, loose mass, as of a fine precipitate.

Food Web—The dependence of organisms upon others in a series for food. The chain begins with plants or scavenging organisms and ends with the largest carnivores.

Gelatinous Matrix—Jelly-like intercellular substance of a tissue; a semisolid material surrounding the cell wall of some algae.

Globular—Having a round or spherical shape.

Hellgrammites (Corydalidae)—Dobson fly larvae. Full-grown larvae are 2 to 3 inches in length; they have a dark brown rough-looking skin, large jaws and posterior hooks. The aquatic larval stage lasts 2 to 3 years. They are secretive and predaceous, living under rocks and debris in flowing water. These larvae are considered one of the finest live baits by fishermen. Pupation occurs on shore, under rocks and debris near the stream edge. The terrestrial adults are short lived.

Herbicide—Substances or a mixture of substances intended to control or destroy any vegetation.

Hepatic Vein—The vein leading from the liver.

Heterocyst—A specialized vegetative cell in certain filamentous blue-green algae; larger, clearer and thicker-walled than the regular vegetative cells.

Hirudin—A substance extracted from the salivary glands of the leech that has the property of preventing coagulation of the blood.

Homothermous—Having the same temperature throughout.

Hypolimnion—The region of a body of water that extends from the thermocline to the bottom of the lake and is removed from surface influence.

Intraperitoneal—Within the peritoneal or abdominal cavity.

Larva—The worm-like form of an insect on issuing from the egg.

Leeches (Hirudinea)—Segmented worms, flat from top to bottom, with terminal suckers that are used for attachment and locomotion. Various species may be parasites, predators, or scavengers; most are aquatic.

Lumen—The space in the interior of a tubular structure, such as an artery or the intestine.

MACROORGANISMS.—Plant, animal, or fungal organisms visible to the unaided eye.

MAYFLY NAIADS (Ephemeroptera).—The immature mayfly. Paired gills are attached on the upper surface of the outer edge of some or all of the first seven abdominal segments. The abdomen terminates in three, rarely two, slender tails. Mouth parts are particularly suited for taking diatoms and scraping decaying plant tissue. The terrestrial adults lack functional mouth parts and live only a few hours.

MENINGOENCEPHALITIS.—An inflammation of the brain and its membranes.

MESENTERIC VEIN.—The large vein leading from the intestines to the abdominal cavity.

MIRACIDIUM.—The ciliated free-swimming larva of a trematode worm.

MORPHOMETRY.—The physical shape and form of a water body.

NON-POINT WASTE SOURCE.—A general unconfined waste discharge, not a point source waste.

NUTRIENT BUDGET.—A quantitative determination of the major nutrients flowing in, retained within, and discharged from a system.

OLIGOTROPHIC WATERS.—Waters with a small supply of nutrients; hence, they support little organic production.

ORGANOLEPTIC.—Affecting or employing one or more of the organs of special sense.

PATHOGENIC BACTERIA.—Bacteria capable of causing disease.

PENSTOCK.—A sluice for regulating flow of water; a conduit for conducting water.

PERIPHYTON.—The association of aquatic organisms attached or clinging to stems and leaves of rooted plants or other surfaces projecting above the bottom.

PESTICIDE.—Any substance used to kill pest organisms including insecticides, herbicides, algicides, fungicides, and bacteriacides.

PHOTIC ZONE.—The surface waters that are penetrated by sunlight.

PHOTOSYNTHESIS.—The process by which simple sugars are manufactured from carbon dioxide and water by living plant cells with the aid of chlorophyll in the presence of light.

PHYTOPLANKTON.—Plant microorganisms, such as certain algae, living unattached in the water.

PLANKTON.—Organisms of relatively small size, mostly microscopic, that either have relatively small powers of locomotion or drift in the water subject to the action of waves and currents.

PLASTID.—A body in a plant cell that contains photosynthetic pigments.

POINT WASTE SOURCE.—Any discernible, confined and discrete conveyance such as any pipe, ditch, channel, tunnel or conduit from which pollutants are or may be discharged.

POPULATION EQUIVALENT.—A means of expressing the strength of a waste by equating it to the strength of waste from an equivalent number of persons.

PROFUNDAL ZONE.—The deep- and bottom-water area beyond the depth of effective light penetration. All of the lake floor beneath the hypolimnion.

PUPA.—An intermediate, usually quiescent, form assumed by insects after the larval stage, and maintained until the beginning of the adult stage.

SECCHI DISC.—A circular metal plate, 20 cm in diameter, the upper surface of which is divided into four equal quadrants and so painted that two quadrants directly opposite each other are black and the intervening ones white.

SEDGWICK-RAFTER COUNTING CELL.—A plankton-counting cell consisting of a brass or glass receptacle 50 by 20 by 1 millimeter sealed to a 1- by 3-inch glass microscope slide. A rectangular cover glass large enough to cover the whole cell is required. The cell has a capacity of exactly 1 milliliter.

SEICHE.—A periodic oscillation of a body of water whose period is determined by the resonant characteristics of the containing basin as controlled by the physical dimensions. These periods generally range from a few minutes to an hour or more. (Originally the term was applied only to lakes but now also to harbors, bays, oceans, etc.)

Seston—The living and nonliving bodies of plants or animals that float or swim in the water.

Settleable Solids—Suspended solids that will settle in quiescent water or sewage in a reasonable period. Such period is commonly, though arbitrarily, taken as two hours.

Sewered Population—The population served by wastewater collecting sewers.

Snail—An organism that typically possesses a coiled shell and crawls on a single muscular foot. Air breathing snails called pulmonates do not have gills but typically obtain oxygen through a "lung" or pulmonary cavity. At variable intervals most pulmonate snails come to the surface of the water for a fresh supply of air. Gill breathing snails possess an internal gill through which dissolved oxygen is removed from the surrounding water.

Species (Both singular and plural)—An organism or organisms forming a natural population or group of populations that transmit specific characteristics from parent to offspring. They are reproductively isolated from other populations with which they might breed. Populations usually exhibit a loss of fertility when hybridizing.

Standing Crop—The biota present in an environment at a selected point in time.

Sublethal Concentration—A concentration in which an organism can survive but within which adverse physiological changes may be manifested.

Suspended Solids—Solids mixed with and generally imparting a cloudy appearance to water, sewage, or other liquids.

Swimmer's Itch—A rash produced on bathers by a parasitic flatworm in the cercarial stage of its life cycle. The organism is killed by the human body as soon as it penetrates the skin; however, the rash may persist for a period of about 2 weeks.

Thermocline—The layer in a body of water in which the drop in temperature equals or exceeds one degree centigrade for each meter or approximately three feet of water depth.

Transection Sampling—Samples collected at defined intervals along an imaginary line connecting two points.

Trophogenic Region—The superficial layer of a lake in which organic production from mineral substances takes place on the basis of light energy.

Tubificids—Aquatic segmented worms that exhibit marked population increases in aquatic environments containing organic decomposable wastes.

Tropholytic Region—The deep layer of the lake where organic dissimilation predominates because of light deficiency.

Water Quality Criteria—A scientific requirement on which a decision or judgment may be based concerning the suitability of water quality to support a designated use.

Water Quality Standard—A plan that is established by governmental authority as a program for water pollution prevention and abatement. Usually it includes a delineation of designated water uses, criteria, and pollution abatement, implementation and surveillance programs.

Zooplankton—Animal microorganisms living unattached in water. They include small crustacea, such as daphnia and cyclops, and single-celled animals such as protozoa.

Appendix

ACRES

Hectares	×	2.471	=	Acres.
Square Meters	×	2.471×10^{-4}	=	Acres.
Acres	×	4047	=	Square meters.
Acres	×	43,560	=	Square feet.
Acre-feet	×	325,851	=	Gallons.
Grams per square meter	×	8.922	=	Pounds per acre.
Kilograms per hectare	×	0.8922	=	Pounds per acre.
Milligrams per square centimeter	×	89.22	=	Pounds per acre.
Milligrams per cubic meter	×	2.72×10^{-3}	=	Pounds per acre-foot.

AREA

Circle = Square of the diameter × 0.7854
Rectangle = Length of the base × height
Sphere = Square of the radius × 3.1416 × 4
Square = Square the length of one side
Trapezoid = Add the two parallel sides × height ÷ 2
Triangle = Base × height ÷ 2

CIRCUMFERENCE

Circle = Diameter × 3.1416

DISSOLVED OXYGEN

Micromoles per liter	×	32×10^{-3}	=	Milligrams per liter.
Millimoles per liter	×	32	=	Milligrams per liter.
Micromoles per microliter	×	32×10^{3}	=	Milligrams per liter.
Millimoles per square meter	×	2848×10^{-4}	=	Pounds per acre.

DOSAGE FORMULA (Chemical)

Length (ft.) × Width (ft.) × Average Depth (ft.) × 62.4 × Desired Concentration in ppm × 10^{-6} = Pounds of active Material Needed.

Speed of Boat (feet per hour) × Width of Spray Pattern (feet) × Depth of Calculated Treatment (feet) × 62.4 × Desired Concentration in ppm × 10^{-6} = Pounds of Active Material Needed Per Hour.

FEET

Fathoms	×	6.08	=	Feet.
Meters	×	3.281	=	Feet.
Acres	×	43,560	=	Square feet.
Square meters	×	10.76	=	Square feet.
Square feet	×	929×10^{-4}	=	Square meters.
Gallons	×	1337×10^{-4}	=	Cubic feet.
Cubic feet	×	7.48	=	Gallons.
Gallons per minute	×	2.228×10^{-3}	=	Cubic feet per second.
Cubic feet per second	×	448.8	=	Gallons per minute.
Million gallons per day	×	1.547	=	Cubic feet per second.
Cubic feet per second	×	6463×10^{-4}	=	Million gallons per day.

GALLONS

Acre feet × 325,851 = Gallons.
Cubic feet × 7.48 = Gallons.
Liters × 2642×10^{-4} = Gallons.
Pounds of water × 1198×10^{-4} = Gallons of water.
Gallons per minute × 1440 = Gallons per day.
Gallons of water × 8.345 = Pounds of water.
Gallons × 1337×10^{-4} = Cubic feet.
Gallons × 231 = Cubic inches.
Gallons × 3.785 = Liters.
Cubic feet per second × 6463×10^{-4} = Million gallons per day.
Cubic feet per second × 448.8 = Gallons per minute.
Gallons per minute × 2.228×10^{-3} = Cubic feet per second.
Million gallons per day × 1.547 = Cubic feet per second.
Parts per million × 8.345 = Pounds per million gallons.

MILES

Kilometers × 6214×10^{-4} = Miles.
Statute Miles × 1.15 = Nautical miles.
Miles × 1.609 = Kilometers.
Nautical Miles Per Hour × 1.0 = Knots.

PHOSPHORUS

microgram atoms phosphorus per gram (µg-atP/g) = 31 parts per million phosphorus (P).

microgram atoms phosphorus per liter (µg-atP/l) = 31 parts per billion phosphorus (P).

phosphorus pentoxide (P_2O_5) × 0.436 = phosphorus (P) equiv.

phosphate (PO_4) × 0.326 = phosphorus (P) equiv.

PARTS PER MILLION

Milligrams per liter × 1.0 = Parts per million.
Grams per liter × 1000 = Parts per million.
Micrograms per liter × 10^{-3} = Parts per million.
Micrograms per gram × 1.0 = Parts per million.
Cubic centimeters per liter × 1.4545 = Parts per million.
Milligrams per gram × 10^{3} = Parts per million.
Cubic millimeters per liter × 1.0 = Parts per million. (volume).
Cubic microns per milliliter × 10^{-6} = Parts per million. (volume).
Parts per million × 8.345 = Pounds per million gallons.

NITRATE (NO_3) × 0.226 = nitrogen (N) equiv.

POUNDS

Milligrams per square meter	×	8922	=	Pounds per acre
Grams per square meter	×	8.922	=	Pounds per acre
Kilograms per hectare	×	0.8922	=	Pounds per acre
Milligrams per square centimeter	×	89.22	=	Pounds per acre
Milligrams per liter	×	2.72	=	Pounds per acre foot
Milligrams per cubic meter	×	2.72×10^{-3}	=	Pounds per acre foot
Micrograms per square meter	×	8.92×10^{-6}	=	Pounds per acre
Acre feet of water	×	2.7×10^{6}	=	Pounds of water
Gallons of water	×	8.345	=	Pounds of water
Parts Per Million × Cubic Feet Per Second × 5.4			=	Pounds per day

(Gallons per minute × 2.228×10^{-3} = Cubic feet per second)

Parts per million × 8.34 × gallons per day × 10^{-6} = Pounds per day

(Gallons per minute × 1440 = Gallons per day)

STANDARD UNITS

Areal standard units = $20\mu \times 20\mu = 400\mu^2$

Cubic standard units = $20\mu \times 20\mu \times 20\mu = 8000\mu^3$

Cubic standard units × 8×10^{-6} = parts per million by volume

VOLUME

Cone —Square the radius of the base × 3.1416 × height ÷ 3

Cube —Cube the length of one edge

Cylinder —Square the radius of the base × 3.1416 × height

Pyramid —Area of the base × height ÷ 3

Sphere —Cube the radius × 3.1416 × 4 ÷ 3

Temperatures—Centigrade to Fahrenheit *

Temp. C	0	1	2	3	4	5	6	7	8	9
0	32.0	33.8	35.6	37.4	39.2	41.0	42.8	44.6	46.4	48.2
10	50.0	51.8	53.6	55.4	57.2	59.0	60.8	62.6	64.4	66.2
20	68.0	69.8	71.6	73.4	75.2	77.0	78.8	80.6	82.4	84.2
30	86.0	87.8	89.6	91.4	93.2	95.0	96.8	98.6	100.4	102.2
40	104.0	105.8	107.6	109.4	111.2	113.0	114.8	116.6	118.4	120.2
50	122.0	123.8	125.6	127.4	129.2	131.0	132.8	134.6	136.4	138.2

* Temperatures in degrees Centigrade expressed in left vertical column and in top horizontal row; corresponding temperatures in degrees Fahrenheit in body of table. (From: Welch, P.S. 1948. Limnological Methods. McGraw-Hill Book Co., Inc.)

Temperatures—Fahrenheit to Centigrade *

Temp. F	0	1	2	3	4	5	6	7	8	9
30	-1.11	-0.56	0.00	0.56	1.11	1.67	2.22	2.78	3.33	3.89
40	4.44	5.00	5.56	6.11	6.67	7.22	7.78	8.33	8.89	9.44
50	10.00	10.56	11.11	11.67	12.22	12.78	13.33	13.89	14.44	15.00
60	15.56	16.11	16.67	17.22	17.78	18.33	18.89	19.44	20.00	20.56
70	21.11	21.67	22.22	22.78	23.33	23.89	24.44	25.00	25.56	26.11
80	26.67	27.22	27.78	28.33	28.89	29.44	30.00	30.56	31.11	31.67
90	32.22	32.78	33.33	33.89	34.44	35.00	35.56	36.11	36.67	37.22
100	37.78	38.33	38.89	39.44	40.00	40.56	41.11	41.67	42.22	42.78

* Temperatures in degrees Fahrenheit expressed in left vertical column and in top horizontal row; corresponding temperatures in degrees Centigrade in body of table. (From: Welch, P.S. 1948. Limnological Methods. McGraw-Hill Book Co., Inc.)

BIO-ASSAY DOSAGE CHART

For Preliminary Screening of an Effluent Waste

Percent of Waste in test jar	Waste added (ml)	Dilution water added (ml)
100	2,500	0
75	1,875	625
56	1,400	1,100
32	800	1,700
18	450	2,050
5.6	140	2,360
1	25	2,475
0	0	2,500
Total (ml)	7,190	12,810
Gallons required	2	3⅜

BIO-ASSAY DILUTION CHART

A Guide to the Selection of Experimental Concentrations, Based on Progressive Bisection of Intervals on a Logarithmic Scale

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5
10.0				
				8.7
			7.5	
				6.5
		5.6		
				4.9
			4.2	
				3.7
	3.2			
				2.8
			2.4	
				2.1
		1.8		
				1.55
			1.35	
				1.15
1.0				

DILUTION TABLE

Concentration Desired			To prepare solutions of concentrations indicated at left, take number of milliliters of stock solution shown below, and make up to one liter with suitable dilution water.				
%	ppm or mg/L	ppb or μg/L	Stock sol: 10% 100 gm/L	Stock sol: 1% 10 gm/L	Stock sol: .1% 1 gm/L	Stock sol: .01% .1 gm/L	Stock sol: .001% .01 gm/L
100.	1,000,000						
10.	100,000		1,000				
5.6	56,000		560				
3.2	32,000		320				
1.8	18,000		180				
1.0	10,000		100	1,000			
.56	5,600		56	560			
.32	3,200		32	320			
.18	1,800		18	180			
.1	1,000		10	100	1,000		
.056	560		5.6	56	560		
.032	320		3.2	32	320		
.018	180		1.8	18	180		
.01	100		1.0	10	100	1,000	
.0056	56			5.6	56	560	
.0032	32			3.2	32	320	
.0018	18			1.8	18	180	
.001	10			1.0	10	100	1,000
.00056	5.6				5.6	56	560
.00032	3.2				3.2	32	320
.00018	1.8				1.8	18	180
.0001	1.0	1,000			1.0	10	100
.000056	.56	560				5.6	56
.000032	.32	320				3.2	32
.000018	.18	180				1.8	18
.00001	.10	100				1.0	10
.0000056	.056	56					5.6
.0000032	.032	32					3.2
.0000018	.018	18					1.8
.000001	.010	10					1.0

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